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Learning pathways for digitally creative youth
a study of 3D animation

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LEARNING PATHWAYS FOR DIGITALLY CREATIVE YOUTH: A STUDY OF 3D ANIMATION

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Contents

List of Tables

List of Figures

Abstract

3D animation is taking an ever increasing role in the development of the media and digital artefacts that children consume. This demands that children are equipped with the tools, skills and critical faculties to be able to create what they consume. Focusing on 3D animation as a means to be digitally creative, this thesis explores the formal learning pathways available through the school system in England, and the knowledge domains behind 3D animation, including research on computational thinking and multimodality. The goal was to understand the role of 3D animation in supporting the development of digital creativity. Three research questions were formulated: 1. What characterises the opportunities for learning 3D animation in the formal curriculum? 2. What are the affordances of 3D digital animation work for young people? 3. What possible connections are there between computational thinking and multimodality in the production of 3D digital animation?

For research question 1, the national pupil database and open access government data were used to examine student choice of GCSE for computer science and media studies, as well as the attainment of students on these courses, considering the role of ethnicity, gender and poverty indicators. For research questions 2 and 3, students that participated in a 3D animation summer camp were interviewed about the reasons behind their subject choices and learning journeys in the camp.

Results showed gender disparity in GCSEs and that opportunities for children to learn computing and media studies in formal settings have decreased substantially since 2013, with gender and socio-economic divides emerging. As digital media takes a tighter grip of everyday lived reality, formal pathways for digital creativity amongst young people appear to be narrowing. Additionally, it was found that young 3D animators had strong support networks. Financial support was necessary in many cases. The factors that impacted student choices of film signifiers involved a mix of hardware limitations interacting with software, time allowed for the work, skill levels of peers, and the often tacit expectations of the camp itself. The research showed that the affordances of 3D animation work for young people are highly dependent on their social circumstances, the limitations of the discourse inherent to curricula, the limitations of the software and those of the hardware used. It also showed that computational thinking concepts such as automation, abstraction and decomposition were seen to heavily influence components of multimodality theory.

In conclusion, this thesis highlights concerns about the development of digital and media literacy through formal education, by providing the first major study of a 3D animation camp and demonstrating the importance of software and hardware in semiotic decision making. It argues that media concepts should be present in computing, and computing concepts present in media studies. This research is important because

it informs curriculum changes and raises questions about the democratisation of digital media.

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I would like to thank my school mentors, without the encouragement of Martin Dixon and Rob McAuliffe I wouldn't have spent so much time messing about with 3D animation in and out of lesson time. The main reason for teaching 3D animation was the interest shown by the students of Christ the King sixth form college, Lewisham.

3Dcamp would have been impossible to run if it weren't for the tireless work of Tom SF Haines and the support of Oliver Bradley-Baker and UCL Engineering's Rae Harbird.

The research would never have been successful if it weren't for the support of the DfE's NPD team and the students on 3Dcamp who gave their time to be interviewed.

I would still be writing this thesis if it wasn't for the encouragement of my wife Susana and the fact that I have two screens in my office allowing Francis to watch "colour horses" and "night time soldiers" whilst I wrote. Sincere thanks to my parents for helping me to value learning. Also thanks to Tita and Tito for their cooking and a quiet space to work.

Ad maiorem Dei gloriam

Ethics Declaration

The studies undertaken in this thesis were submitted for ethics consideration under the references EDU 15/ 091 and EDU 16/ 110 in the School of Education, and were approved under the procedures of the University of Roehampton's Ethics Committee in July 2016.

I hereby declare that this thesis represents my own work; the material included in this volume has not been submitted wholly or in part for any academic award or qualification other than that for which it is now submitted. It has correct use of sources, references and quotes, and contains all relevant literature which has been used in the reference list.

List of abbreviations

- AQA = Assessment and Qualifications Alliance
- BAME = Black, Asian and minority ethnic
- BBC = British Broadcasting Corporation
- BCS = British Computer Society
- CS = Computer Science
- CSTA = Computer Science Teachers Association
- DfE = Department for Education
- DfES = Department for Education and Skills
- DL = Digital Literacy
- EAL = English as an Additional Language
- ICT = Information and Communication Technology
- ISTE = International Society for Technology in Education
- IT = Information Technology
- JCQ = Joint Council for Qualifications
- M = Mean
- MAC = Migration Advisory Committee
- Nesta = National Endowment for Science, Technology and the Arts
- NRC = National Research Council
- OCR = Oxford, Cambridge and RSA Examinations
- Ofcom = The Office of Communications
- Ofqual = The Office of Qualifications and Examinations Regulation
- SD = Standard Deviation
- STEM = Science, Technology, Engineering and Mathematics
- STEAM = Science, Technology, Engineering, Art and Mathematics
- VFX = Visual Effects

1 Introduction

This chapter outlines the main motivations for undertaking this research, situating it within the current educational landscape and areas of research. It then takes the reader through the use of terminology and finishes by giving an outline of each chapter of the thesis.

1.1 Problem statement

I was a secondary school computing teacher in a deprived area of London in 2005. Students displayed a range of interests and competencies in digital technologies, with the majority being interested in the digital art part of the curriculum. For many students who struggled with English, digital art provided them with a means to express themselves. At first 3D animation might have seemed very complicated for secondary school students, but with appropriate scaffolding I was able to get students as young as 11 making animations in the spirit of animations they might see on a low budget television series, see figure 1.1. This links in directly with the democratic idea behind the use of digital technologies, that consumers of media can now become creators (Buckingham & Sefton-Green, 2005).

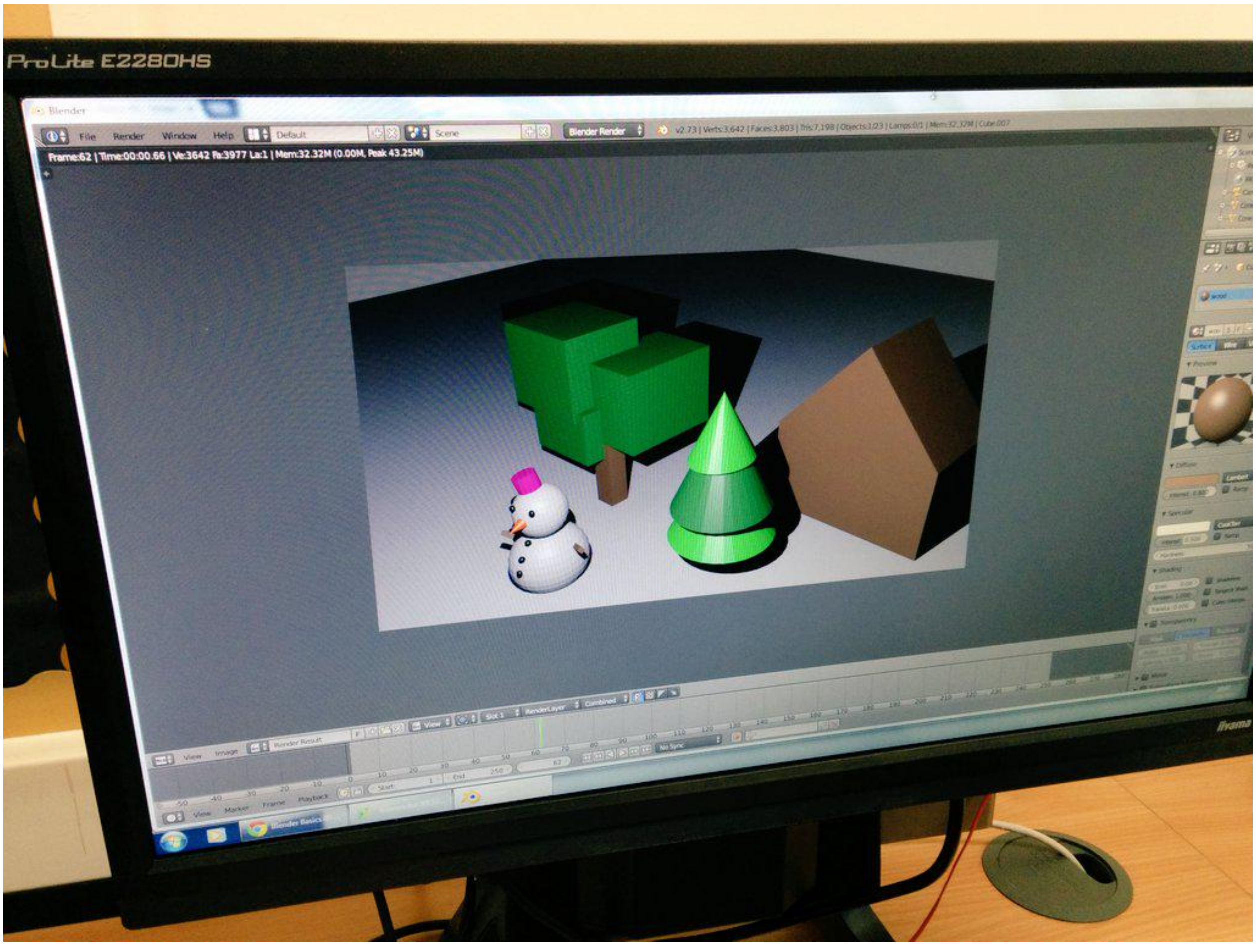

Figure 1.1: Example of student output

I moved job to work at a Sixth Form college. I saw that the digital art interest of many of the students was outside what was taught in the classroom and for those who attempted work with 3D, their work was often unrewarded by the exam system. In some cases the high quality work was penalised as it did not fit neatly into the rubric of equivalent 2D work. Speaking to students about their career aspirations, for many, digital art was an area they were very keen to get involved in. However, the college offered limited support for nurturing this interest. I decided to give them a range of skills that the industry would be interested in and give them experience of 3D animation that would help them make better choices about their own education and careers. Students making the right subject choice for their futures is noted as a problem area for students who want to be digitally creative (Sefton-Green & Brown, 2014).

Returning to the lessons I had learned in secondary school, I set up a 3D animation club and had 10-15 students attend every Wednesday lunchtime to work together and share their work. Through structured discussion and showcasing of good practice, students started to produce exceptional output, of a calibre seen in some areas of the graphics design industry (see figure 1.2, below). I attempted to get one of the students an internship with a company that supported the college. The company were unable to help. After much searching, I found a placement at Teach First where the student produced work that was used in official marketing material. This difficulty in getting placements for students would be instrumental in setting up a digital art summer camp, with 3Dcamp being launched in 2012.

Figure 1.2: Student commissioned work for Teach First

I decided to run the school club again the next year and focused on getting students to work in small teams. There was huge enthusiasm for the club, but many students dropped out shortly after starting, appearing to lack the resilience needed to master the basics of the software. The software used was a product called Blender, with a steep learning curve (more on choice of software will be presented in the *Software* section). Tutorials to support the beginner user range in quality, few of them were aimed at 16 year olds, and many of them used complex language beyond the language abilities of many of the interested students. Several of the students were doing poorly in other subjects, but found that 3D animation was something they could excel at. Their success at 3D animation greatly influenced their university choices with some of them getting preferential admission criteria based on their 3D animation portfolios. The students also became runners up in the University of Manchester's annual Animation Competition (see figure 1.3).

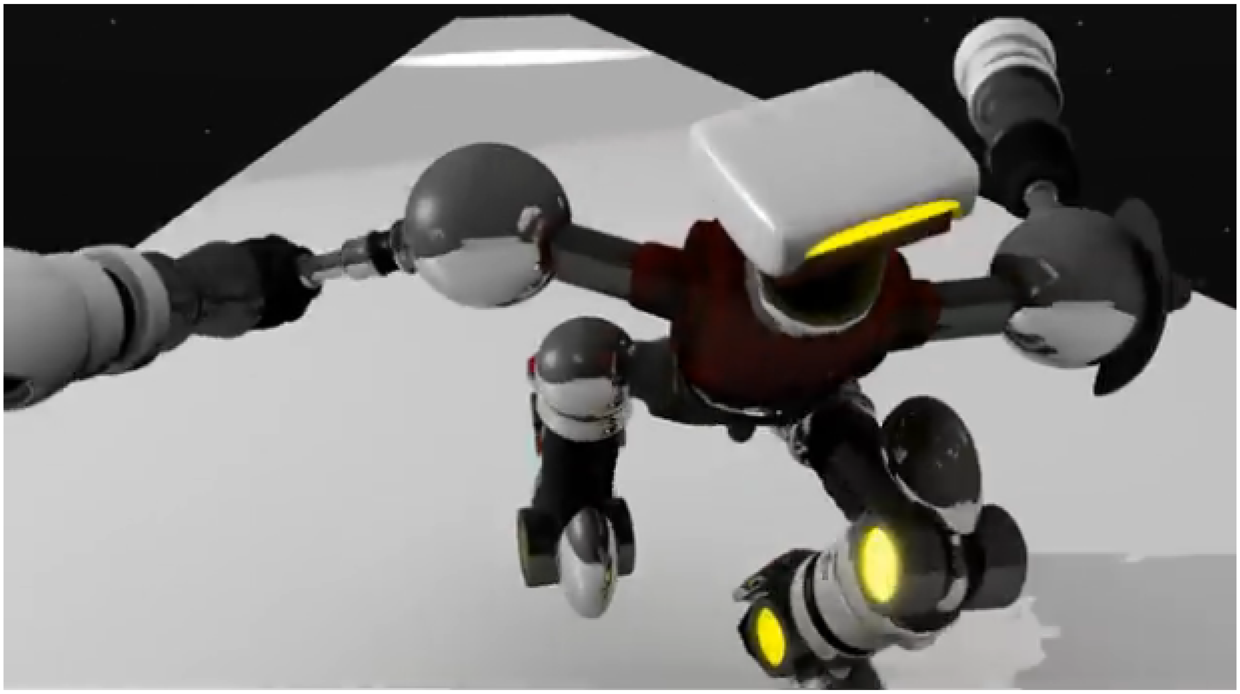

Figure 1.3: Frame from student entry to Manchester Animation competition: *Turing*[1]

Looking again for summer placements, I approached the University of Manchester to see if their sponsors would be willing to host some students for summer internships. Unfortunately the sponsorship agreements didn't extend to placements and I decided to provide my own, through setting up 3Dcamp, the UK's first 3D animation summer school. Borrowing some computers from the college and setting them up in central London office space with a colleague, we ran a school for 13 students. Realising that the students were coming to the event with a range of skill sets, I focused on getting students to work with each other in solving problems, rather than having lectures that might not be applicable to everyone. This environment allowed students to learn skills from each other, with the staff getting involved if necessary. The output was impressive and students appeared to learn a lot in the process. Several students used this experience to apply for university courses and apprenticeships.

Having taught both coding and digital art, I saw that many students prefer one to the other. Thinking about my own personal experience, I chose to become a teacher as I didn't want to spend my career coding. Unfortunately the debate has largely shifted to coding being good and other skills being less useful (e.g. Gove, 2012), or even digital skills being inherent in students growing up as 'digital natives' (Prensky, 2001). Research into digital natives (e.g. Helsper & Eynon, 2010; Selwyn, 2009) and my own experiences, suggest that students rarely acquire these skills on their own, unless someone teaches them or creates an environment for them to learn in. My fear is the shift to coding will negatively impact the life chances of many aspiring digital artists, especially those from working class backgrounds. Additionally, a broader range of students attended the camp when compared to similar ‘coding’ camps, with ethnic minority, female and working class students better represented. A focus on digital art, or “creative” computing appeared to have greater appeal to a wider variety of students than computer science (Wong & Kemp, 2018). Learning pathways for digitally creative youths remain largely undocumented, especially in the area of 3D animation (Sefton-Green, 2013).

For the reasons above, I have chosen to focus this thesis on 3D digital animation. Some attempts have been made to study the use of 3D digital animation in a school environment, but so far the studies have been exploratory, focusing more on teaching coding than animation (e.g. Cooper, Dann, & Pausch, 2000; Dann, Cooper, & Pausch, 2008), university based (e.g. Aoki, Joel, Ursyn, & Pollak, 2017; Aoki & Koning, 2011), or limited in scope (e.g. Lin et al., 2017; Jörg et al., 2014).

3D animation is clearly within the domain of *digital* creativity. This raises questions about what makes digital creativity different from other forms of creativity, how 3D animation fits into definitions of digital creativity, what affordances 3D animation offers school children and what constraints exist in their engagement with 3D animation. In short, we need to better understand the role of 3D animation in supporting the development of digital creativity.

1.2 A note on terminology

Whilst there are clear parallels between 3D digital animation and traditional animation (Lasseter, 1987), 3D digital animation is different from traditional animation in the sense that it uses computers to create the models and animations, whilst traditional animation might use the manipulation of clay and film cameras. Where 3D animation is used in this thesis it is referring to 3D *digital* animation, not traditional forms of animation such as stop motion.

When looking at 3D digital animation we are looking at a form of digital creativity that spans many subject domains. Firstly there is the use of digital technology, which might fit into a traditional Information and Communication Technologies (ICT) course. Secondly, my work with students and 3D digital animation has noted similar computational thinking skills to those being learnt through programming and computer science (CS) (Kemp, 2014a), placing 3D digital animation into the realm of computing and computer science as commonly understood (DfE, 2013). Thirdly the storytelling elements and artistic expression of 3D animation links to media and film studies as well as English, arts and graphics. You might also link the design elements of 3D digital animation with some of the design elements of design and technology courses; as well as the mathematical skills that can be incorporated into the creation of related digital artefacts. This hybrid course fits well into the STEAM (science, technology, engineering, *arts* and mathematics) agenda (Maeda, 2013).

For the purposes of this thesis I focus the research on the subject domains of computing and media studies, whilst admitting that other interpretations of the subjects related to 3D animation could have been chosen. Where the word *computing* is used, it should be taken to mean a subject encompassing the three elements of computer science, information technology and digital literacy (Furber, 2012). Computer science here can be understood as the content and skills of the GCSE exam, which cover areas such as programming, ethics, hardware, software, data representation, databases, networking and computational thinking. Topics such as programming are directly tested through written exams and practical programming sessions (e.g. OCR, 2012). However, it should be noted that several sources referenced in this thesis use the words computing and computer science interchangeably.

The summer camp described in this thesis is a non-profit organisation which focuses on running digital making summer camps. These camps bring together students aged 11-18 to make their own 3D digital animations. It was set up in 2012. Throughout the thesis it is referred to as *3Dcamp*, not the real name of the organisation.

Throughout the thesis the term gender is used to designate sex differences, as this is the term adopted by the national pupil database.

1.3 Organisation of the thesis

This thesis is organised into 8 chapters. There is no separate methodology chapter, with studies one and two (chapters 6 & 7) having their own methodology subsections. I now describe the contents of each chapter:

Chapter 2 - Mood board outlines the current research on digital learning pathways in England, with a particular focus on computing and the digital arts. It outlines the reasoning for curriculum choices and the criticisms of such choices. The idea of creativity is explored using Csikszentmihalyi's (2013) *systems model*, in particular I look at how the *domain*, *field* and *person* are represented in other literature about creativity. Similarities are drawn between the systems model and Bourdieu's (1986) concept of *capital*. I explore the literature about what it means to be *digitally* creative covering several definitions of the term (e.g. Hugill & Yang, 2013; Sefton-Green, 2013).

Chapter 3 - 3D animation, semiotics and computational thinking delves into the components that make up the knowledge and skill *domain* of 3D animation. I start by outlining the argument for studying *3D* animation and situating it within the literature that define computing and media studies. I cover theory from film and media, focusing on *multimodality* (Kress & Van Leeuwen, 2001) and the *kineikonic chronotope* (Burn, 2013); as well as theory from digital making: *computational thinking* (e.g. Wing, 2008). The chapter concludes by looking at theories about the use of software in creating 3D digital animations, and how tools can limit and enable creativity; it outlines a social understanding of how software choice can impact the *internal* and *external* representation of creative work.

Chapter 4 - Curriculum: content, pedagogy and assessment describes a curriculum suitable for digital creativity, looking at what content should be included, what pedagogy should be used and how these things should be assessed. Within the description of a creative pedagogy it outlines how *constructionism* (Papert & Harel, 1991), a theory of computing pedagogy, maps to creativity. Next, the digitally creative curriculum is mapped to the summer camp being studied, and an outline of the workings of the camp is given. It ends by looking at how the summer camp uses computational thinking to produce films.

Chapter 5 - Objective and research questions sums up the focus of the research studies and outlines the questions being asked.

Chapter 6 - Study one - A national picture of computing education using the NPD analyses access, participation and attainment in digitally creative subjects present in the English education system. The focus here is on the media studies and computer science courses at GCSE, which, I argue, provide some of the skills needed for becoming digitally creative through 3D animation. The findings show poorer schools are less likely to offer computer science courses. Within these schools poorer female students are more likely to sit the subject. Girls under perform at computer science and over perform at media studies when compared to boys of similar abilities. Both subjects are in decline in terms of total hours being taught in schools meaning pathways for digital creativity are narrowing within formal education.

Chapter 7 - Study two - 3Dcamp: computational thinking, creativity and multimodality from the students' point of view analyses the student film creation process against the concepts of *capital*, *computational thinking* and *multimodality*. It looks at the learning pathways of students, exploring family, social and educational backgrounds, finding that students have very little formal 3D animation education, but are supported by family, friends and teachers; additionally students consider the mixture of arts and technology as being a better environment for engaging females. Computational thinking was exhibited by all students, with automation being a key component of 3D animation, that isn't always present in other discourses around computational thinking. 3D animation also allows for rich discussions around efficiency and computing limitations that are absent from similar level programming based courses. Students are heavily influenced by existing culture in their choice of film discourse. The discourse of the camp itself, i.e. what students think they are expected to make, impacts their choice of film discourses, design and production. Additionally, I argue that 3D animation and other digitally made media needs to look to incorporate computational thinking as a key factor that impacts multimodal choices, I outline examples from the camp.

Chapter 8 - Finale: conclusion of the research, listing the limitations of the two studies undertaken, implications for policy and practice, and potential future research that could build on this thesis.

Although I don't have a specific methodology chapter, a broad methodology is outlined in chapter 5, and the studies covered in chapters 6 & 7 include bespoke methodological sections.

2 Mood board

In this chapter I present the key concepts, theories and pathways behind creative digital making. The focus of this section is largely on educational opportunities available to students aged 11-18.

First, a rationale for the formal curriculum in England is outlined. I present arguments for a more inclusive Science, Technology, Engineering and Mathematics (STEM) education involving the combination of STEM and arts education, also known as STEAM (A = Arts) (e.g. Catterall, 2017). Within a formal educational setting I look at the broad subject areas that encompass 3D animation, I interpret this as studying computing and the arts. I cover arguments for the study of both subject areas (e.g. Livingstone & Hope, 2011) along with descriptions of recent changes in the curriculum and their impact in uptake of these subjects by students (e.g. Steers, 2014).

Recent arguments for the inclusion of computing in the English national curriculum are outlined, looking at the rationale for the economic (e.g. Gove, 2012) benefits of the subject, along with the disparities in access to the subject amongst vulnerable groups, including females, certain ethnicities and poorer students (e.g. Kemp, Berry, & Wong, 2018). The shift in England's national curriculum from ICT to computing is described, along with data on the initial impact of curriculum change within England's schools. In particular I focus on current research around female participation and achievement in computing, outlining reasons for observed disparities (e.g. Varma, 2010). These reasons include a lack of creative interpretations of computing, differences in female interests, and average female subject strengths lying outside STEM subjects such as computing (Stoet & Geary, 2018). Using the theory of self-efficacy (e.g. Huang, 2013), I argue that the shift towards computing will mean that girls will identify as being less able in the subject than they would have done if more creative digital courses such as ICT were being offered. I cover recent changes in accountability measures for English schools, with the government excluding arts education from the top tier of subjects. This exclusion has been linked to the decline of the subject in schools.

I discuss the social issues that inhibit individuals from engaging with digital creativity, looking at and dismissing Prensky's (2001) idea of the digital native. I look at literature around young people's digital making, finding that support networks for students are essential (Sefton-Green & Brown, 2014). I outline the inequalities present in the digital workplace, in particular finding issues with gender balance (e.g. Myers, 2018), an imbalance that starts to emerge at school age (e.g. Kemp et al., 2018). Within the English school system computer science courses show one of the lowest representations of female students. I note other inequalities in access to digital courses at school, focusing on computing and media courses, and access by region and ethnicity. I finish this section by describing the current economic need for a digitally creative workforce (Djumalieva & Sleeman, 2018).

The second part of this chapter explores definitions of creativity. I focus on Csikszentmihalyi's (2013) systems model of creativity, further exploring his concepts of the domain, field and person, linking each in with other creativity research. I make connections between the systems model and Bourdieu's (1986) theory of capital, arguing that they talk about many of the same concepts. I delve further into the multiple definitions of digital creativity, outlining how each of them link back to Csikszentmihalyi's systems model. I look at Sefton-Green's (Sefton-Green, 2013) study of digital creativity in the school system and outline each of his four points about what makes digital creativity and linking them back to other creativity research.

2.1 Digital learning pathways in England

This section looks at the arguments for the inclusion of digital learning in the formal curriculum. It briefly outlines the qualifications available to students from 16-18, incorporating a broad definition of digital learning that leans on the idea of Science, Technology, Engineering, Arts and Mathematics (STEAM) education. It provides a critical examination of issues surrounding the delivery of an equitable digital education.

2.1.1 STEAM

In the 1990s the acronym STEM was created to bring together the subject areas of Science, Technology, Engineering and Mathematics, with technology often standing in for computing (Sanders, 2008). Following the wide held belief that the United States of America (USA) was falling behind in STEM education, a national movement was founded to promote STEM education (Catterall, 2017), with parallels to earlier movements in the UK (e.g. Snow, 1959). STEM education continues to receive widespread publicity and government support with national STEM strategies and non-governmental organisations set up to support STEM learning (Marginson, Tytler, Freeman, & Roberts, 2013).

Movements to increase uptake in STEM subjects have not been without issue. Catterall (2017) argues that there aren't equitable opportunities for engagement in STEM, with "deep institutional biases" (p.1), especially against women. Amongst the STEM subjects, computing sees the lowest female uptake amongst English secondary school children (JCQ, 2017b). Dangelmaier and Hermann (2017) argue that traditional methods to engage females with STEM don't work and that people need to recognise the similarities between science and art as a way to engage more females. Conventional STEM has been seen to leave too many people behind. The addition of art can invigorate the subject (Robelen, 2011), as well as supporting student wellbeing through increasing empathy (Catterall, 2017, p. 4). Educationalists argue that the addition of the arts to STEM reveals more creative and engaging pedagogies (e.g. Sefton-Green, Thomson, Jones, & Bresler, 2011; Catterall, 2017; Colucci-Gray et al., 2017; Long, Robert, & Davis, 2017). Pressure for STEAM also comes from business, with UK creative industries emphasising the need to look at the practical applications of science and mathematics, whilst maintaining links with art (Henley, 2012). Building on the economic reasoning for STEM, Catterall argues that adding Art to the STEM subjects will support the economy (Catterall, 2017), Maeda sees the addition of art as being key to future innovation: "art and design are poised to transform our [USA] economy in the 21st century like science and technology did in the last century" (Maeda, 2013, p. 2).

Across the globe the number of art subject students now using computer programming or scripting has grown substantially since the late 1990s (Manovich, 2013). The addition of the Arts to STEM creates *STEAM*, although the conception of what 'Art' means is subject to debate (Colucci-Gray et al., 2017).

2.1.2 it's the economy, stupid

> Britain also has exceptional talent in technical fields such as audio-visual effects and computer graphics. It is important that the government does everything it can to ensure that there continues to be a flow of home grown talent through our education system into this area, as it continues to grow in importance within Britain's Creative and Cultural Industries. (Henley, 2012, p. 19)

One of the most common arguments for the need for children to study computing is that the economy needs more digitally skilled workers. For example, Gove (2012) said "the UK had been let down by an ICT [Information and Communication Technology] curriculum that neglects the rigorous computer science and programming skills which high-tech industries need" and the Edge foundation (2008) commented, "Over half of digital businesses report that vacancies are hard to fill and this costs the UK economy an estimated £63 billion per year". UK Government occupation shortage lists show digital skills as amongst the most needed for the economy (MAC, 2015). It certainly appears that there are Information Technology (IT) jobs available and that there is a need for digital skills in the workforce. However, when we look at the numbers of students sitting degrees in computing each year we find that computing is one of the largest subject areas and that computing students are amongst the least employable of all STEM graduates. The reasons for the high levels of unemployment are varied and include students expecting that by studying computer science they would easily be able to get a job, so they became complacent in their studies (BIS, 2016). Sefton-Green & Brown (2014) note that poor employability is also the result of students making bad career choices. Additionally, students taking degrees in areas of digital creativity and the arts also struggle to find employment, the reason being a mix of poor courses and bad subject choice decisions that don't suit student skills or allow them to access jobs. Often VFX (Visual Effects) firms look abroad for talent (Sefton-Green & Brown, 2014, p. 21).

The reasons for the placing of computing, and especially coding, in the curriculum are also open to question. Do we want a subject that reflects the needs of industry, and how do the needs of industry match the needs of children? Rather than asking schools to train students to work in industry, shouldn't business be doing more to support current graduates (and non-graduates) to be job ready? Even if we agree that schools should be teaching skills needed by the tech sector, is computer science, and especially programming, the most suitable skill to focus on (Rudd, 2013)? A recent Nesta report (Djumalieva & Sleeman, 2018) lists animation and multimedia as the most promising digital skills for the future workplace, yet, the curriculum change in England has resulted in animation and multimedia skills, once common in ICT, no longer being part of computing exams.

2.1.3 Computing in schools

Computing has been a subject in English schools since the 1980s when it was established with the support of the BBC (British Broadcasting Corporation) Computer Literacy Project (Blyth, 2012). The children who had access to a computing education during that time have helped to create modern industry, with recent analysis finding that the UK had the largest percentage of coders who learnt coding between the ages of 5 and 10, the majority being in their 30s and 40s, placing their interaction with computing firmly within the time of the BBC project (Hackerrank, 2018).

The BBC initiative finished and the subject curriculum ICT was created in the 1990s, with a focus on using computers, rather than finding out how they worked (Brown, Sentance, Crick, & Humphreys, 2014). By the late 2000s ICT was falling out of favour with industry, government and students. Reasons for this were given in the Royal Society's (Furber, 2012) "Shutdown or Restart" report, where it was noted that ICT students were learning little beyond "basic digital literacy" due to limited teacher competence and a very limited interpretation of the national curriculum. They proposed a new course, computing, comprising digital literacy, information technology and computer science. They also suggested that computing should be taught in every school, with every student having the opportunity to study it.

Nesta (Livingstone & Hope, 2011) looked at the importance of computing to the visual effects and games industry in the UK. However, the report made very little mention of the wide range of digital skills used in the industry being applicable to secondary school level, recommending instead that computer science be put into the national curriculum and recognised by the English Baccalaureate (EBacc).

The last iteration of the English ICT curriculum was published in 2007 (QCA, 2007) and the course was disestablished in 2013 (Gove, 2012), being replaced by a new subject, computing (DfE, 2013). Computing places more emphasis on computer science and programming, with less of a focus on how to use computer applications (Brown et al., 2014). The introduction of computing was accompanied by the creation of a new General Certificate in Secondary Education (GCSE)[2] in computer science, where topics such as programming, would be directly tested through written exams and practical programming sessions (e.g. OCR, 2012). In September 2017 the GCSE in ICT was discontinued (DfE, 2015a), leaving students who are interested in a computing GCSE no option other than to study computer science.

The change in curriculum in England has been closely observed by other countries looking to learn lessons from the implementation (e.g. Caspersen, Gal-Ezer, McGettrick, & Nardelli, 2018; Informatics Europe, 2014; Moller & Crick, 2018). There was early speculation that the introduction of computer science would create an elitist and selective subject (Rudd, 2013), and more recent concerns that a move away from the more 'creative' ICT programmes of study and a focus on technical computing in computer science, such as the emphasis on programming, "could generate another level of the digital gender divide, even among those who are digitally skilled" (Wong & Kemp, 2018, p. 302).

Initial analyses of the new computer science GCSE show that it is failing to attract girls in similar numbers to the legacy ICT qualification (Kemp et al., 2018, 2016; Royal Society, 2017). Student numbers taking the new computer science GCSE have increased each year since its introduction (albeit matched to a decrease in numbers taking ICT), but at the same time girls as a percentage of all computing students have decreased (2013: ~40%; 2016: ~32% Kemp, 2017; 2017: 30% Kemp et al., 2018). This decrease can be attributed to the male dominated GCSE computer science making up a larger proportion of all GCSE computing qualifications, and the more equitable GCSE ICT decreasing in representation. In 2017, for computer science, around one in five (c. 20%) GCSE students and one in ten (c. 10%) A-level[3] students were girls, compared to two in five (c. 40%) for ICT (JCQ, 2017b, 2017a). Black and working class students are also underrepresented in computer science qualifications compared to ICT, and to the national cohort (Kemp et al., 2018). When girls do sit ICT and computer science GCSE, they outperform boys in average grades (Kemp et al., 2018, 2016).

The Royal Society's (2017) report on computing found the main reason given by girls for not choosing to study computer science was "Not interested in subject", with 55% of girls giving this response, compared to 38% of boys. The reasons for the small numbers of girls sitting the course and for this response are likely to be complex, involving a mix of sociological and psychological factors. I cover some of these below.

There are psychological differences between male and female populations (Schmitt et al., 2017) with much debate around how these differences emerge. This debate is outside the scope of this PhD; instead, I

[2] a national examination normally taken at age 16
[3] a national examination normally taken at age 18

outline the psychological factors that are correlated to participation and attainment in computer science (currently the only qualification available in computing (Kemp & Berry, 2019) and the core of the computing curriculum (DfE, 2013)). Existing studies suggest that computer science is more appealing to the average male (e.g. Royal Society, 2017). Some literature shows that boys are more likely to command top grades at degree level (Wagner, 2016), and other literature indicates that girls outperform boys at school level computer science (Kemp et al., 2016).

Having outlined the context for computing in English schools, I now look at female involvement and achievement in computing.

2.1.3.1 Female participation in computing In most western countries, girls generally engage with technology just as much as boys and there are few reported gender differences in terms of internet or social media usage (Ofcom, 2015). However, in schools, there is a low female uptake of computer science qualifications (Kemp et al., 2018; Royal Society, 2017), a pattern seen at degree level in the UK and other developed countries (Wagner, 2016). More broadly, there are concerns that girls lack educational and career aspirations in computer science, which is often considered to be gendered as a male domain (Wong & Kemp, 2018). These gendered discourses are often reinforced by parents, teachers and the media (Cohoon & Aspray, 2006; Sefton-Green & Brown, 2014; Vekiri, 2013). The disparity in representation is not universal, with cultural factors appearing to create environments for high levels of female CS participation in some non-western countries, including at degree level (Vitores & Gil-Juárez, 2016).

ICT focuses on the knowledge and application of 'office productivity' and other end-user software, which is likely to have wider appeal as generic and transferable digital skills that are valued in many workplaces. ICT is often regarded by students as a generic skill-set, rather than as a specific career pathway, which remains somewhat reserved for the tech savvy, typically male, candidates (Lasen, 2010).

Computer scientists, and those who are tech savvy, are often portrayed in the media as male geeks or nerds, who embody specific characteristics, such as being highly logical and clever, but also stubborn and socially inept (e.g., Varma, 2010). These images help to reinforce the idea of computer science as a predominantly male domain and maintain rather than challenge the dominant gender paradigm and roles (Butler, 1990).

From an early age, girls and boys are likely to be socialised with different expectations and interests (Margolis & Fisher, 2003; Varma, 2010). For example, boys are typically expected to be more technical, risky and adventurous than girls, who are socialised into roles that tend to make safer choices, and be more creative and caring (Francis & Skelton, 2005). The characteristics of computer science seem to align more with the attributes expected of boys, as programming is generally considered as a technical activity. Stereotypical ideas around gender and computer science may also be facilitated through gender-specific toys and leisure activities, such that computer games are typically targeted at boys whereas more passive and caring toys (e.g., dolls) are typically marketed to girls (Scantlebury & Baker, 2013).

Although studies have suggested that there is now better gender equality in terms of digital access and technology interest (Vekiri, 2013), others have found gender differences in terms of frequency and types of computer use, as well as self-efficacy and aspirations in digital technology (e.g., Margolis & Fisher, 2003; Varma, 2010; Wong, 2016a). Boys appear to use computers more for gaming, whereas girls seem to use computers and the internet more specifically for social media (Drabowicz, 2014). Stoilescu and Egodawatte (2010) also found that girls are generally less interested in coding, even amongst undergraduate computer science students. Furthermore, girls continue to self-report lower confidence in their CS abilities than boys. Computer science is generally considered by young people, particularly girls, as challenging and tedious (Lasen, 2010; Vekiri, 2013).

The Royal Society (2017) noted that girls studying in single sex schools were more likely to sit GCSE computer science than those attending mixed gender providers; additionally, female GCSE CS cohort sizes in single sex schools are greater than those in mixed gender institutions (Kemp et al., 2018), although it should be acknowledged that girls' schools are less likely to offer GCSE computer science than mixed providers (ibid.). It has been shown that all female computer science classes at high school may result in better attitudes towards the subject, when compared to mixed classes (Crombie, Abarbanel, & Trinneer, 2002). This contrasts with other findings that all girl CS engagement events were less likely to keep girls interested in CS than mixed events (Quigley, 2017). Whilst poorer students are less likely to study GCSE computer science than ICT, when combining gender and ethnicity with poverty indicators, 2015 data shows that among female students, those from working class backgrounds made up a larger proportion of the female cohort than working class boys make up of the male cohort. This pattern is even more apparent for working class Asian[4] and Chinese girls (Kemp et al., 2016). This suggests a complex mix of cultural and socio-economic factors influencing female uptake of computing.

High attainment in mathematics is associated with increased uptake of GCSE computer science (Kemp et al., 2018; Royal Society, 2017), with some schools using mathematical attainment as a filter for entry to a computer science GCSE (Kemp et al., 2016), but how this differs between male and female populations is currently unclear and explored in this thesis.

Students with special educational needs were over-represented in the A-level computer science qualification.

[4]Asian does not include ethnically Chinese students in the National Pupil Database

However, what functioning profiles these students had remains unclear (Kemp et al., 2018). One explanation might be the propensity of autistic individuals to take computing qualifications. Boys make up the majority of autistic individuals (e.g. Brugha et al., 2009; Constantino & Todd, 2003), and autistic traits are correlated to an increased interest in mathematics, science and computer science (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). Supporting this, autistic traits have been shown to correlate with an interest in hacking (Schell & Melnychuk, 2011). Baron-Cohen (2009) claims that autism is an example of the *extreme male brain*, with autistic traits existing on a continuum where boys are more likely to demonstrate them. It follows that *if* autistic traits are linked to an increased interest in computer science, *and* boys are more likely to have autistic traits than girls, *then* from a purely psychological perspective boys will on average be more likely to be interested in CS than girls. However, this finding should be taken with caution, as biology is not the only factor that impacts a person's interests and other studies suggest that the true number of autistic girls is underreported (Gould & Ashton-Smith, 2011). If female autism manifests itself differently to male autism, then it might be the case that girls might be as interested in digital subjects if they come in a format that they find attractive.

One variable that might be relevant to understanding female participation in computing is self-efficacy, understood as one's belief in their own ability to succeed at something. Self-efficacy is highly correlated with choice of study and career (Beyer, 2014; Hur, Andrzejewski, & Marghitu, 2017). Huang's (2013) meta-analysis of studies into self-efficacy showed that boys were more likely to possess greater self-efficacy in computer science. Self-efficacy is reinforcing, success helps increase it and failure can undermine it (Schunk, 1991; Schunk & Pajares, 2002). Stoet and Geary's (2018) international study of science, mathematics and reading attainment, hypothesizes that girls often use their relative performance in a subject to influence their educational and career choices. Even where girls perform better in science and mathematics than boys, they will on average choose the reading related pathway if that is where their relative strength lies, i.e. if they perceive themselves to be better at reading than at science and mathematics. The majority of girls were shown to be better at reading than science and mathematics, for boys the relative strengths were in science and mathematics and not reading. This complements other research (Wang, Eccles, & Kenny, 2013) that shows that people with high mathematical and verbal skills are more likely to pick non-STEM careers than those who have high mathematical but moderate verbal skills. Girls make up a larger percentage of the high mathematical and high verbal group and are thus less likely to follow a STEM career. Whilst it has been shown that girls outperform boys in computer science GCSE (Kemp et al., 2018), it is currently unclear how male and female performance in computer science and ICT compares to other subjects. This is explored in this thesis.

2.1.3.2 Female attainment in computing There have been several studies that have looked into the effect of gender on academic performance, but few have focused on computer science or programming. At university level, Wagner's (2016) study of English computer science undergraduate results from multiple institutions over the course of 12 years showed significant underachievement for women compared to men in obtaining first class degrees (the highest qualification level), a difference that was not present in any other subject area. However, she found no significant differences in computer science for higher grades in general, i.e. 2:1 and 2:2 grades. Initial analysis of GCSE computer science shows girls more likely to command the highest grade (A*) in 2014 (Bramley, Rodeiro, & Vitello, 2015) and high grades (A*-C) in 2015 and 2017 (Kemp et al., 2016, 2016) than their male peers. At A-level (national examinations generally taken at age 18) girls tended to outperform boys (DfES, 2007), including in computer science in 2015 (Kemp et al., 2016), although in 2017 boys outperformed girls (Kemp et al., 2018). It should be noted that girls outperform boys in nearly all subject areas (Bramley et al., 2015; Richardson, Abraham, & Bond, 2012; Voyer & Voyer, 2014), and, whilst girls might outperform boys at mathematics or science, they typically show a stronger relative performance in literacy (Stoet & Geary, 2018).

At degree level larger female CS cohorts were correlated with a decrease in average performance among women (Wagner, 2016). Bramley et al. (2015) found that regardless of a subject being mainly studied by men, women tended to do better in exams. However, this research looked at final grades and didn't control for the ability of entrants, i.e. how did students do in a subject compared to their grades in other subjects. Additionally, the impact of single sex providers on secondary level computer science performance has not been studied. I cover both these factors in this thesis.

Computer science is considered to be one of the harder subjects at GCSE, with students typically getting lower scores than in most other disciplines (Ofqual, 2016). The reasons for this remain unclear, although the relatively recent introduction of the subject at GCSE and the inclusion of computer science on the national curriculum may well be contributory factors. How females and males perform when controlling for their ability in other subjects remains unclear, and it will be covered below.

Reasons for female underperformance might include Baron-Cohen's (2009) *empathising-systemising* theory, that states that boys are, on average, better at systemising, and girls, on average, are better at empathising. A *system* being "anything which is governed by rules specifying input-operation-output relationships [...] such as [...] computer programming" (Baron-Cohen, 2004, p. 97). The ability to systemise has been correlated with increased ability in hacking (Bolgan, Mosca, McLean, & Rusconi, 2016), and Baron-Cohen's theory (ibid.) suggests that, from a purely psychological perspective, the average male would be more suited to courses that have large components of programming, such as computer science. However, studies into programming outcomes show no specific gender differences. Wilson (2002) found no difference between male and female performance in programming tests and Lau and Yuen's (2009) study of 14-19 year old students found no differences in performance between genders when controlling for student ability. However, as noted above, girls tend to outperform boys in all subjects and male relative strength lies in STEM subjects (Stoet & Geary, 2018), which would be consistent with Baron-Cohen's model.

Personal factors that can shape success in programming include self-efficacy and ability in mathematics (Byrne & Lyons, 2001; Wiedenbeck, Labelle, & Kain, 2004; Wilson & Shrock, 2001). For programming, it has been shown that females can feel more inadequate, frustrated and with a lower level of self-efficacy compared to males when solving the same problems. With increased self-efficacy corresponding positively with programming outcomes (Lishinski, Yadav, Good, & Enbody, 2016). Several studies have linked spatial abilities to increased performance in computing and programming (Ambrosio, Almeida, Macedo, & Franco, 2014; Cooper, Wang, Israni, & Sorby, 2015; Fincher et al., 2006). Male students are, on average, better at spatial reasoning (Reilly, Neumann, & Andrews, 2017), with increased exposure to testosterone being correlated with better performance in spatial reasoning tasks (Aleman, Bronk, Kessels, Koppeschaar, & Honk, 2004).

GCSE computer science has one of the largest gender imbalances of all subjects, with only ~20% of students in 2017 being female (Kemp et al., 2018). It might follow that the girls taking the subject have overcome significant barriers to entry, meaning those sitting GCSE computer science are particularly suited to the subject . Wagner (2016) tests a similar hypothesis when looking at girls taking CS degrees, but as noted earlier, finds that females underperform at the highest degree level. At GCSE, girls are more likely to command the highest grades in computer science (Kemp et al., 2018). Bramley et al. (2015) show GCSE gender grade differences are generally smaller for science technology engineering and mathematics (STEM) subjects than they are for the arts and the humanities, including computer science in the STEM categorisation. They also show that girls are slightly more likely to outperform boys at ICT than they are at computer science. This matches DfES (2007) data that shows girls less likely to outperform boys at A-level computer science than at ICT. However, Wagner, Bramley et al. and the DfES fail to control for the academic profile of the students sitting the exams, i.e. does the small number of girls taking computer science mean that they, as a group, are more academically able than the larger more representative male group? Does the data support and supports theories around male relative strength lying in STEM and female strength lying elsewhere (Stoet & Geary, 2018)? The relationship between gender, academic ability and performance in GCSE computer science is explored in the following sections.

2.1.4 Arts (and humanities) in schools

Snow (1959) argued that western society was becoming increasingly split into two cultures, the sciences and the humanities. A disconnect between these cultures was stunting progress, in particular a lack of scientific knowledge was holding back human development: “[scientists have] the future in their bones” (p.10).

More recently the English education system has focused on encouraging the uptake of specific sets of qualifications through the deployment of the *Progress 8* school assessment measurement and the English Baccalaureate (EBacc) grouping of subjects. This means that schools are now judged on how students perform in a core set of subjects split into three ‘buckets’. Mathematics and English make up the first bucket and are double weighted, the second bucket sees students choosing three subjects from science, computer science, history, geography and languages, and the final bucket is made up of all the other subjects. Art and art related subjects sit in this final ‘bucket’ (DfE, 2014). The shift in curriculum appears to have moved away from the arts. And where art qualifications are still being run, curriculum reform has shifted the focus of the arts more on appreciation and tradition, rather than contemporary art and the creation of art (Steers, 2014). The importance of the arts in the curriculum hasn’t been helped by organisations such as the Russell Group (2016), who don’t list art as one of their *facilitating subjects*, that is a subject that will help you getting into a wide range of university courses.

This lessening of importance for the arts in the curriculum has coincided with a decline in numbers of hours of art taught between 2011 and 2015 (Worth & De Lazzari, 2017, p. 7). With predictions that Progress 8 becoming the main accountability measure in schools, will drive schools to drop arts based courses.

What is the argument for including the arts in a school curriculum? Colucci-Gray et al. (2017) argue for the inclusion of arts into STEM, because the arts bring a roundedness to education, engaging with the human side of creation. “As such, it is argued that the arts retain their legitimacy as specific and equally valuable perspectives on the world” (p.31). Leavis (1962) goes further, arguing that Snow (1959) is wrong in his assumption that there are two cultures. For Leavis these is only one culture, the humanities; the sciences are tertiary to this. It is through the humanities that we find significance to our lives. The pursuit of economic ends on their own is an empty pursuit without the meaning that makes human life worth living. To try and equate the two cultures, e.g. comparing the second law of thermodynamics to Shakespeare is misplaced, “There *is* no equivalent” (p.73).

Burn (2013) argues that a curriculum built on subject domains “cuts across the multimodal relationships of authentic cultural forms like film and games, and each domain tends to privilege its own modes” (p.320). It follows that the assessment of schools based on ‘buckets’ of discrete subjects might discourage the teaching of cross domain new media modes such as 3D animation, which don't fit neatly into any specific domain and straddle the knowledge and skills used in multiple domains (Sefton-Green, 2013). Whilst art and humanities will continue to be taught, albeit to a lesser extent than before, the structure of education and the way it is judged might prohibit schools from embracing newer modes of expression.

2.1.5 Social distinctions

The *digital native* is a term popularised by Prensky (2001). Digital natives are people who have grown up surrounded by technology and therefore they are "native speakers" of digital technology. This might imply that students, by growing up in houses with tablet computers, games consoles and the internet, with tools to create multimedia, will be doing so naturally. Therefore we might question the need to teach students how to create films and 3D animation, as they should be able to pick this up themselves or might be doing so already. However, we cannot treat all students as the same, they have different levels of access to technology and different experiences with technology (e.g. Helsper & Eynon, 2010). Even when students have access to the internet at home, do they actually have access to it when they need it, and how do they use it when they are given access? In 2017, 88% of 12-15 year olds had internet access through a desktop/laptop/notebook at home, but only 82% used it (Ofcom, 2017). Whilst increased computing skills are linked to increased pay (Tech Nation, 2019), social mobility through computing is rare (British Computer Society, 2018). More worryingly is the emerging divide amongst those students studying computer science at school, with students from more affluent backgrounds being far more likely to study the subject (Kemp & Berry, 2019; Kemp et al., 2018).

There is a clear 'digital divide' between students in terms of access to technology. The digital divide might be between children of different ages and cultures, rich and poor (Ofcom, 2015). Or there might be a digital divide between how different genders engage with technology (Wong & Kemp, 2018). Whilst a teacher during their career might come across one or two students with exceptional digital skills, they need to recognise that "young people's engagements with digital technologies are varied and often unspectacular" (Selwyn, 2009). And this means that there is a need for teaching digital skills to 'digital natives'; and for teaching media skills to those immersed in media. Cultural capital plays a large role in critiquing and creating media artefacts (Buckingham, 2003) and notes that "despite the falling cost of equipment, the 'digital divide' between rich and poor continues to widen" (summarising Selfe (2000), cited in Buckingham, 2003, p. 174). In their study of two Silicon Valley middle schools Barron, Walter, Martin, & Schatz (2010) found that whilst most students had access to some form of computing tools at home, the digital divide emerged through the differing uses of technology amongst students. Quinlan (2015) found that young digital makers in the

UK were most likely to be digitally making when they were in a formal classroom setting, with 66% of respondents giving that answer in 2015 declining from 78% in 2013 (p.20). Sefton-Green & Brown (2014) note that "All children/young people [who were digital makers] needed at least one 'support system' – family, school, extra-curricular – in order to progress" (p.14) and that the support system for working class students was most likely to be teachers "a resource that of course is not available to everyone" (ibid.). Even when home access to technology is low, increasing access to mentors and digital tools can help in making students digital makers, increasing engagement in: "programming, music creation, graphic design, and other creative production activities" (Barron et al., 2010, p. 179).

Buckingham (2003) frames student produced media artefacts in terms of gender; with females and males groups typically responding to the interpretation of media artefacts in different ways. Burn and Durran (2007) note different choices made in a student's approach to media creation, heavily influenced by their gender identity.

The computing industry is dominated by males, with only 31% of employees at *Facebook* and *Apple* being female (Myers, 2018), and only 25% of all tech jobs in the UK being filled by women (Tech Nation, 2019). The gender balance within the animation industry is more balanced with 40% of employees being female in 2018 (O'Connor, 2018), and more recently Box, Cooper, Smith, Devereux, & O'Connor (2019) finding that females make up 51% of animation, 34% of VFX and 46% of post production roles [p.8]; with all roles involving significant computing skills. The increase in female participation in 'creative' computing is supported by recent findings on school students and 3D animation which found that females were more likely to be attracted to interpretations of computing that were seen as being more artistic and less technical (Wong & Kemp, 2018). It is also supported by other research that shows females to be more likely to study 'creative' computing courses at school (Kemp et al., 2018). Female students appear to be substantially less interested in digital making than boys (Quinlan, 2015, p. 39), matching female perceptions of computing (Royal Society, 2017).

Computer science GCSE and A-level were two of the most gender imbalanced subjects taken in 2017, with females representing 20% and 9% of the population respectively. This is compared to 48% of GCSE and 56% of A-level Media students being female (JCQ, 2017b, 2017a). Access to computing and media education differs between regions in England (Kemp et al., 2018). For example in 2017 access to a computer science GCSE ranged from 55.8% of providers in the North West of England to 47.3% of providers in the West Midlands, with 76.8% of students nationally being in a school that offered the subject (p.80). Data on provision of Media Studies GCSE is more limited with Kemp et al. (2018) reporting that in 2017 only 39.5% of students were in a school where the GCSE was offered (p.80). For the A-level qualification, Media studies was on offer in institutions serving 60.5% of the student population, compared to 57.2% for computer science (p.86). Only 15.5% of the students who could take GCSE CS actually did, for Media studies this figure was 16.8% (ibid. pp.80-86).

There appear to be substantial differences in the ethnic makeup of students sitting CS and Media courses. White and Black students have better relative representation in Media studies at both GCSE and A-level, whilst Chinese students are four times more likely to be sitting GCSE CS than GCSE Media (ibid. pp.109-117). When looking at poverty indicators, poorer students are more likely to sit Media than CS at both GCSE and Alevel (ibid. pp.104-107). Amongst professionals working in the animation industry, only 8% were from a Black, Asian, Minority Ethnic (BAME) background; this compares to 15% of the digital workforce in the UK (Tech Nation, 2019).

A-level exam results for both subjects showed that females outperform males at the highest grades, in line with findings about the general population (Bramley et al., 2015). However, the difference between genders was much greater for Media than that for CS, with males almost matching female grades in computer science (Kemp et al., 2018, p. 98). This suggests that gendered factors that impact educational outcomes are less pronounced in Media than CS; this might be due to differences in cohorts, e.g. female CS students are relatively weaker than their peers taking Media.

Provision of computing qualifications varies between different parts of England, with 13% of students in the North West studying computer science, compared to 10% of students in Yorkshire and the Humber (Kemp et al., 2018, p. 36). Quinlan (2015) notes the regionally uneven spread of digital making opportunities with larger clusters of provision in London and the South East. Film and television production is concentrated in London and the South East, whilst animation appears to be concentrated in London and the North West (O'Connor, 2018).

There is an economic argument for the promotion of creative computing education (Djumalieva & Sleeman, 2018) predicting that the demand of animation jobs will grow substantially in the near future. The animation industry employs over 10,000 people in the UK, with the majority of job roles being hard to fill using the current workforce. However, around half of these jobs remain freelance (O'Connor, 2018) and any school based economic arguments for the teaching of animation should recognise and make clear the fragile nature of work in this area.

Having outlined the state of computing and media education, I now turn to defining creativity and describing how the skills related to 3D animation fit into a creativity framework.

2.2 Creativity

The definition of creativity is contested with different definitions emerging from parties including policy makers, artists and industry (Banaji, Burn, & Buckingham, 2010). This chapter looks at the component ideas of creativity, looking for disagreement and consensus. I focus on Csikszentmihalyi's (2013) *systems model* of creativity, making connections with other thinkers in this space and making links with Bourdieu's (1986) idea of *capital*. I focus in particular on the *field* and *domain* components of Csikszentmihalyi's model to provide a structure for evaluating creativity in formal and informal education. Looking specifically at 'digital' creativity, I argue that the definition is often undefined within educational settings, with common interpretations linking it to 'making', art and technology.

2.2.1 Outputs and types

Robinson (2011) describes creativity as "creating original ideas that have value" (p.2). I use this phrase as a starting point for this section of the thesis. Firstly, what is meant by original ideas? Robinson offers us a definition of imagination, where imagination is the process of bringing about images that one hasn't experienced before. For example, one might imagine a time travelling bicycle or a red swan. Our original ideas merely repurpose the memories of previous experience into new combinations; we have met the colour red and the bird swan previously. Bringing all these components together leads to the creation of something new. The newness of the creation is also important for Vygotsky (2004), who states that "[a]ny human act that gives rise to something new is referred to as a creative act" (p.7).

Once an original idea has been produced then Robinson (2011) stresses that these ideas must be brought into reality for them to be designated creative, they cannot live solely in one's mind. You might have an original idea in your head, but it cannot be creative unless you convert that idea into something tangible. For example, one might think of a new design for a jet engine, but unless it is written down and/or manufactured then it cannot be termed as creative. Robinson describes the process of creativity as "applied imagination", you have to do something with your imagination to bring it into the world of other people. But is this the case? Vygotsky (2004) differs in his interpretation. A creative idea remaining inside the person's head without any external knowledge of it is enough. Imagine that my conscience is wracked by the problem of the existence of evil in the world; over the course of several nights I come up with a novel solution. This satisfies me and allows me to continue my life without ever sharing the secret. This creative act helps no-one but me, but it is a new idea that changes my life.

So why is there this conflict in definition? Returning to Robinson's (2011) definition of "creating original ideas that have value" (p.2), it is clear that we can be creative in a way that has value for the individual involved or society in general. Craft & Jeffrey (2008) define two types of creativity: high and ordinary. High creativity is socially recognised to be world changing in its impact and rare in its occurrence. Instances of high creativity might include Einstein's theory of relativity or Zuckerberg's invention of *Facebook*, events that change how people live in and understand the world. In comparison, ordinary creativity concerns nearly all individuals and the creative acts they perform on a daily basis to solve problems that impact their lives. It follows that some of the problems that people face daily might be purely internal and therefore ordinary creativity might not need a public output. Though it is likely that many solutions would have an external outcome. High creativity is based in a world of social validation, to impact others it must be understandable in some form by others, and therefore does require an external product to be produced. A similar model is the Big-C/little-c distinction in forms of creativity (Lubart, 2010, p. 269) and the psychological (individual focused) versus historical (society changing) creativity of Boden (1999). Figure 2.1 illustrates this distinction.

Figure 2.1: Ordinary and high creativity and the relationship with value

Creativity is what has driven forward human progress, from the invention of the wheel to the development of the computer and as such creativity can be seen as a driving force for the betterment of society (Csikszentmihalyi, 2013). But is it so easy to separate high creativity/Big-C from ordinary creativity/little-c? The creative act of one individual might be for their own survival, but it might also act on their family, community, country or continent. Take the case of an artist, A, as technically accomplished as John Singer Sargent, but lacking the same social recognition. How can we separate A's achievements from a child painting for their mother? Kaufman & Beghetto (2009) suggest a splitting of little-c creativity into mini-c and pro-c creativity. Mini-c creativity recognises the everyday creativity of an individual, whilst pro-c creativity recognises skill and creativity of a professional who doesn't reach Big-C creativity.

The creative category of an act may not be easy to distinguish, as its significance to local and global populations varies due to social and cultural factors (Csikszentmihalyi, 2013, p. 313). A parallel can be drawn here with Bakhtin's (Pearce, 1994, p. 4) concept of dialogics. Bakhtin states that "[m]any people who have an excellent command of a language often feel quite helpless in certain spheres of communication precisely because they do not have a practical command of the generic forms used in the given spheres" (Bakhtin, 1986, p. 80). Mapped onto creativity, someone might have mastered the language of a particular domain (mathematical symbols, artistic conventions etc), as well as any accompanying psychological traits to be creative. However, they haven't mastered the language needed for their creative act to be accepted by the wider world. The failure to surmount the social and cultural factors that surround a creative act could easily mark the difference between pro-c act and Big-C. It must also be recognised that the factors affecting the categorisation of a creative act are also dependent on the time in which the creative act is performed. The *chronotopic* (Bakhtin, 1981) nature of a creative act means that a person living in one time frame and its accompanying socio-cultural factors, might be considered mini-c creative. The same creative act produced in a different time would be considered Big-C creative and vice versa. Csikszentmihalyi (2013) notes that once an artefact is finished by a creator, its significance is up to the society into which the artefact has been placed. An example of the chronotopic nature of creativity is the work of Vincent Van Gogh, whose genius was largely only recognised after his death. The chronotopic nature of creativity can also be seen in science, with Lord Kelvin regarding x-rays as an elaborate hoax as it conflicted with the perceived knowledge of the time (Kuhn, 2012, p. 59). It is only through major paradigmatic shifts that science progresses and Kuhn (2012) notes that "scientists [do not] aim to invent new theories, and they are often intolerant of those invented by others" (p.24). It is perfectly possible that the work of a Big-C creative individual might not be discovered for generations, or that a creative act with the potential for Big-C creativity might never be discovered at all due to sociocultural factors or sheer bad luck. The chronotopic nature of creativity is visible working in the opposite direction as well, where the societal impact of a creative act recedes or disappears. The Ptolemaic astronomical system was a great creative act and hugely influential for centuries before it was cast aside in favour of the Copernican system (ibid.).

In addition, one small act might help lead to greater creative acts in the future, and without these ordinary creative acts, highly creative acts might not occur at all, as Vygotsky (2004) states: "[w]hen we consider the phenomenon of collective creativity, which combines all these drops of individual creativity that frequently are insignificant in themselves, we readily understand what an enormous percentage of what has been created by humanity is a product of the anonymous collective creative work of unknown inventors" (p.5). Thus the difference between the definitions of little-c and Big-C creativity could be seen as blurred ones.

2.2.2 A framework for creativity

Kozbelt et al. (2010) recognise "Four (or Six) P's of Creativity" (pp.24-25). These are facets of creativity that are emphasized by a range of writers:

- *Process* - mental mechanisms involved in being creative
- *Product* - what has been made
- *Personality* - cross-domain skills of creative individuals
- *Place/Press[ures]* - "the setting or climate where an individual resides"
- *Persuasion* - how people change the mind of others working in a similar area

The items above can be categorised into one final facet: performances and *potentials* (Runco, 2003). Performance encompasses creative products and the persuasion that accompanies their acceptance by others. Potentials encompass the factors that influence the product and persuasion, namely the personality of the individual creator, their circumstances and pressures placed upon them, and the creative process that they undertake.

A range of theories of creativity have been proposed that address one or more of the creative facets listed above (Kozbelt et al., 2010). Taking each of the above to be important, systems theories see creativity "not as a single entity, but as emerging from a complex system with interacting subcomponents - all of which must be taken into account for a rich, meaningful, and valid understanding of creativity" (p.38). The evolving systems approach focuses "less on understanding the particulars of a specific creative act than on how those particulars fit into the context of an individual creator's goals, knowledge, and reasoning, as well as larger social forces and creative paradigms" (ibid. p.38). This links with Bakhtin's (1986) idea of the dialogic, placing the language of a creative act into a socio-cultural setting. Csikszentmihalyi (2013) adds to this stating that: "Psychologists tend to see creativity exclusively as a mental process [but] creativity is as much a cultural and social as it is a psychological event" (p.3). What does the sociocultural context consist of? Czikszentmihalyi (1999, 2013) proposes a systems theory that can be broken down into the domain, field and person, where:

- *Domain* - the culture and language that makes up an area of interest. For example, in Computer Science this might include programming concepts such as loops and selection, hardware concepts such as gate logic notation, as well as the 'hacker culture' of using websites such as stackoverflow to solve programming problems
- *Field* - the individuals or gatekeepers that accompany an area of interest and validate any innovations in a domain. For example, a young artist might be involved with their teacher, the local art club and

the Tate gallery.

- *Person* - the individual who acts on the domain and interacts with the field to make some sort of change that is accepted by the field. This is the individual performing the creative act.

We can map mini, pro and Big c onto the field and domain axis: the distinction between mini-c and pro-c is their understanding of the domain, and that Big-C can occur from a mini-c and pro-c starting point. The Big-C arrows suggest an increase in the domain axis through a creative act; note that the changing opacity of the Big-C arrows suggest that Big-C creative acts are more common for individuals better connected with the field and more knowledgeable of the domain. My attempt to perform this mapping can be seen in figure 2.2.

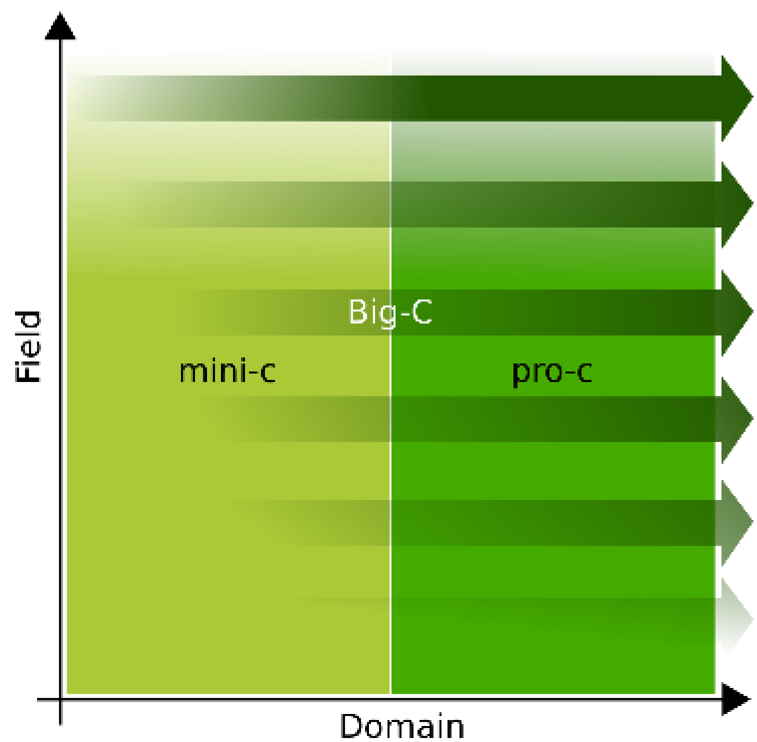

Figure 2.2: the relationship between different forms of creativity and the field and the domain, the darker arrows signify the increased likelihood of changing the domain, correlated with better knowledge of the domain and of the field

Each of Czikszentmihalyi's areas will now be explored:

2.2.2.1 Domain Domains can be seen as cultural memes that evolve over time (Csikszentmihalyi, 2013). As memes, they require the ability to make copies of themselves through the passing on and adaptation of ideas and techniques. It is difficult to make changes to a domain without first internalising the language of the domain, this language allows us to make sense of a domain as well as to judge when something is nonsense and can be discarded (Robinson, 2011, p. 148). If a child is particularly gifted at maths, without learning the symbolic language of mathematics, they are highly unlikely to be able to contribute anything new to the field (Csikszentmihalyi, 2013). Not only would they lack the ability to communicate any novelty they had discovered to the wider field, they would also be unable to learn so readily from others. Without a strong foundation in the language and rules of the domain, it is unlikely anything new will be developed. As argued earlier, people cannot be expected to imagine out of nothing. It is therefore necessary for people to have a rich set of previous experiences that they can slot together in new ways (Vygotsky, 2004). It has been observed that significant time expenditure is required for people to function as a high level/Big-C creative individual. A rough 10 year rule for someone to become an expert in their field has been observed across multiple domains, with this expert knowledge allowing individuals to become more efficient at representing and solving problems (Ericsson & Charness, 1994). In addition, it has been seen that for more creative individuals the "greater the number of associations that an individual has to the requisite elements of a problem, the greater the probability of his reaching a creative solution." (Mednick, 1962).

Children are commonly seen to be creative individuals who, through certain forms of education, unlearn how to be creative (Robinson, 2011). Tolstoy (quoted in Vygotsky, 2004) appears to take this one step further. After working with children on creative writing he noted: "I am convinced [to be creative], we must not try to teach children in general and particularly peasant children how to write and compose" (p.47). Suggesting that such techniques would stifle the innate creativity of the child. Vygotksy criticised this conclusion; it was not the children's isolated voices Tolstoy was hearing, they were voices nurtured through his interaction with them, where Tolstoy had shown them the techniques and shared his excitement. Creativity required a form of education. Vygotsky concludes: "This is education in the precise meaning of the word" (p.51). Robinson (2011) cites Picasso stating that all children are born as artists and they then grow out of being artists. Vygotsky (2004) can be seen to take issue with this idea as well, stating that children go through different levels of development in their creation of drawings, and it is when the child's ambition exceeds their capability to draw that they give up on becoming an artist. Through suitable education in art, this disconnect between ambition and skill would not occur and children would be capable of further creativity. This applies to any domain, once someone's aspirations exceed their current competency, they may well give up. Gardner's (1993) position contrasts with the idea of high/Big-C creativity in children: "[e]arly in life most children give the appearance of engaging in original or novel behaviour [...] However [...] genuinely original or novel activities can come about only when an individual has achieved mastery in the field where he has been working" (p.304).

Being a person having inspiration is most probably not enough to be highly creative and mastery of your subject is necessary. Czikszentmihalyi's research (2013) deals mainly with a small group of people who practice high creativity and for them in depth knowledge of their domain helps them to look for areas where they can add new ideas. This high level of creativity exists in those who have mastered a subject, a position that for most fields, children would struggle to attain. Returning to the idea of ordinary/little-c creativity, inventing novel solutions to problems that concern an individual does not require complete mastery of a field. For example, a child might learn enough about algebra to work out how many sweets they can buy using their pocket money plus money earnt from a few hours of house chores. This isn't world changing, but a child would be showing a level of ordinary/little-c creativity in taking control of their own environment, as well as progressing towards the mastery that is needed for high level/big-C/pro-c creativity.

An education in the domain of a subject can be good for creativity, as it provides the knowledge necessary to master the domain. However, it depends on the type of education that is being delivered. The education provided should aim to excite and inform students, making sure that it keeps pace with their aspirations (Csikszentmihalyi, 2013). The speed of learning a domain is important, and creativity can be inhibited if someone is overloaded with new knowledge or skills. Once a set of skills has been internalised then they can be used without 'focal awareness'; this means a user can reference and make use of them without using their full attention to do so. Their attention can then be focused on mastering the next skill or using the skill to create something new (Robinson, 2011). The idea of the creative individual working alone is a common one, but the reality is different; creative individuals generally work with other people and in all cases base their work on the ideas and findings of others (Csikszentmihalyi, 2013), they are "literally standing on the shoulders of giants".

2.2.2.2 Field For a domain to be changed, the proposed changes must be accepted against the standards of the domain. The "gatekeepers" of whether these standards have been met or not are the field, people working in the domain (Csikszentmihalyi, 2013, p. 23). For example, if a scientist wanted to change their domain with a new scientific theory, they would publish their work in a scientific journal. For a work to be published in a journal it would have to pass peer-review, the process of other people from the domain's field reading and approving the article for reliability, methodology, references to previous work etc. Without approval of these people there would be no publication and it's likely that there would be no change to the domain. Other domains might have less formulaic processes to get new knowledge added to the domain. In the case of an aspiring animator, their teacher might see their work and invite them to join a club, once the other club members might approve of their work, allowing the young animator to join with other animators in making a short movie. This movie would then be submitted to a firm who would either accept or reject the animator's job application.

Without the recognition of the field, it is hard for a person's creative output to spread beyond themselves. For young people this is especially important as the encouragement of older members of the field can help them stay working in a particular domain (Csikszentmihalyi, 2013, p. 332). If we look again at the distinction between types of creativity, it is clear that as someone moves from ordinary to high creativity, they are expanding the scope of the field, from self, through local, national and into potentially international networks of individuals.

Experience of the skills and techniques of an industry, along with knowledge of the views and opinions of practitioners within these industries are essential in becoming creative (Henley, 2012). It is not enough to be skilled in the domain's language, you also have to know about what is acceptable and what is not. Simonton (1988) argues that to be creative you need to be able to change other people's minds.

2.2.2.3 Access to the domain and field Vygotsky (2004) quotes Ribot's observation that whilst creativity might happen in the lands of 'primitive' people, it is in 'civilized' societies where it is much more prevalent. For example, if Mozart were to be born on Christmas Island in 1756 instead of Salzburg, then according to the definition above of high creativity, he would not have had the opportunity to be as highly creative as he was. The domain into which he was born would not be as conducive to fostering his talents as Enlightenment Austria, where he grew up with a notation system to learn from, pass on and record music, technologically advanced instruments, the availability of a musical education and a culture that funded music creation and distant dissemination. This isn't just an argument between the benefits of various countries, it can be extended to groups within societies, with Vygotsky (2004, pp. 30–31) noting that "The privileged classes supply an incomparably greater percent of scientific, technical, and artistic creators".

New technologies bring new opportunities for creative work (Robinson, 2011), with computers opening up opportunities for anyone to access the skills and knowledge necessary to access a domain (Csikszentmihalyi, 2013, p. 338; Manovich, 2013, p. 11). However, access to technology isn't universal (Ofcom, 2015), and even when present, access doesn't necessarily mean that people will use it to be creative. Other people might be capable of understanding a domain but are never given the chance through lack of education, or not having enough money to buy the necessary books and tools (Csikszentmihalyi, 2013, p. 53). In science education, those students most likely to study science at post-16 were also most likely to have parents with scientific qualifications or careers (Archer et al., 2014a).

I have already noted the myth of the lone creative. Robinson (2011, p. 211) supports this and notes that creativity is normally driven by collaboration and making connections. To access the field, an individual must understand how to communicate with the field. This includes internalising the language of the domain including the "techniques, views and influences" of influential members of the domain (Henley, 2012). Access to mentors is seen as especially important in bringing young creatives into a domain (Csikszentmihalyi, 2013, p. 332). But for 'digital making': "[t]hose without the support of middle-class families, for example, were highly reliant on engaged teachers, a resource that of course is not available to everyone" (Sefton-Green & Brown, 2014, p. 14). Individuals can struggle to gain access to their domain's field and often accessing these individuals is reliant on good connections such as being from a more affluent background, or sheer luck. It might even be the case that a potentially creative individual just doesn't have the communication skills necessary to change a domain. (Csikszentmihalyi, 2013, p. 55).

2.2.2.4 Person Studying the psychological and developmental attributes of creative individuals is a common area of creativity research. Some personal characteristics such as an individual's intrinsic motivation, wide interests, openness to experience and autonomy seem to be good indicators of creativity in all domains (Kozbelt et al., 2010, p. 25). Whilst mastery of knowledge appears to be key to creativity within that domain, the growing complexity of an established domain can lead to over specialisation or even "cultural fragmentation such as described in the biblical story of the building of the tower of Babel" (Csikszentmihalyi, 2013, p. 9). Bringing different concepts together is often key to forming new ideas and creative problem solving (Estes & Ward, 2002).

Traditional IQ tests are correlated to creative ability, but beyond an IQ of 115 other factors play a stronger role in predicting creative ability. Beyond childhood, IQ and creativity are largely independent of each other (Kozbelt et al., 2010, p. 15). The environment that a child grows up in strongly influences the creative ability of that child. Those with creative parents are more likely to show creative attributes themselves. Families that expose their children to diverse experiences and give their children moderate amounts of independence are more likely to produce creative offspring (Albert & Runco, 1999).

The creative process involves failures accompanied by personal insights and interpretations (Robinson, 2011, p. 153). The more ideas someone has, the greater the chance that the ideas will be original (Richards, 2010). Simonton's (2003) stochastic model of creativity shows how chance is used in creating new ideas and validating them through the field. As creators do not normally control the gatekeepers for any given domain (Csikszentmihalyi, 2013, p. 23), then "mass production is the optimal strategy for those seeking eminence" as it increases the chances of a creative act being accepted by the field (Kozbelt et al., 2010, p. 36). Economic theories (Kozbelt et al., 2010, p. 30) suggest that large groups inhibit ideation, due to people's fear of being different from the crowd, and whilst experimentation might happen within a small domain, experts are often less willing than non-experts to challenge their own views. Tolerance of new ideas, difference and failure are key to supporting creativity (Florida, 2002). Where tolerance isn't so freely available, it is clear that a creative individual will have to show persistence, motivation and strength of character.

Divergent thinking is often linked to creativity. However, moderation is important: "too much divergent thinking leads to irrelevant ideas that are not creative in the sense of being both original and useful" (Kozbelt et al., 2010, p. 36). Similarly, autonomy is linked to creative acts but without focus, direction and even constraints, autonomy may lead nowhere (Burn, 2009; Csikszentmihalyi, 2013; Robinson, 2011).

Whilst much can be done to change the psychological attributes of an individual and hone them for creative practice: "It is easier to enhance creativity by changing conditions in the environment than by trying to make people think more creatively" (Csikszentmihalyi, 2013, p. 1). Additionally, the environment can be hugely influential for creative action, with "the drive to create is always inversely proportional to the simplicity of the environment." (Vygotsky, 2004, p. 30).

2.2.3 Capital

> I would suggest that young people can only become more creative by learning distinct skills (the 'tools of the trade') and by learning about the techniques, views and influences of great writers, artists, film-makers and musicians (Henley, 2012, p. 18)

A person's place within society and their ability to reposition themselves can be understood as a relationship between themselves and the 'capital' that they possess (Bourdieu, 1986). Capital describes a person's exposure to, knowledge of and possession of resources that relate to an area of endeavour; it can take many forms and here I look at how the idea of 'capital' can be mapped to creativity and specifically 3D digital animation. It is important to note that capital itself has very little value without a complementary field on which the knowledge and experiences can act (Archer, Dawson, DeWitt, Seakins, & Wong, 2015).

Whilst traditionally cultural capital was seen to align closely with the arts, more recently the definition of capital has shifted to incorporate technology and science (e.g. Prieur & Savage, 2013; Archer et al., 2015). Parallels can also be drawn between Csikszentmihalyi's (2013) *systems model* of creativity and Bourdieu's theory (Bourdieu, 1986) of social reproduction, through the use of *capital*[5]. Fulton and Paton (2016) suggest that combining the two models "provide[s] a comprehensive account of creativity". Specifically looking at the different forms of capital:

- *social capital* - the support network to aid domain acquisition and support knowledge of the field.
- *symbolic capital* - recognition of a person's achievement that help position them within a field

[5] note that Bourdieu uses the term field more loosely than Csikszentmihalyi

- *economic capital* - financial support to help access the domain through paying for courses and resources
- cultural capital - a person's grasp of the domain

More recently, Archer et al. (2015) have extended Bourdieu's theory to outline a specific "Science capital". This model suggests specific attributes seen to be supportive of an individual's access to science. Whilst Archer et al. also note that although the model proposed might not map perfectly onto other areas, the model can be used to help flesh out a capital model for 3D digital animation. For example, *Scientific literacy* maps to the skills and knowledge involved in 3D animation skills, *Scientific-related dispositions / preferences* maps on to how useful and important students see 3D digital animation being to their lives, and *Symbolic Knowledge About the Transferability of Science in the Labor Market* maps on to the knowledge of 3D animation job market, education routes and routes into careers, etc.

2.2.4 Digital Creativity

Now that I have addressed the idea of what it means to be creative, the focus moves to what it is to be *digitally* creative, that is, to be creative with computing devices; and how does this differ from being more generally creative. The English National Curriculum specifies that computing education: "equips pupils to use computational thinking and creativity to understand and change the world" (DfE, 2013, p. 1), but doesn't specify what it means by creativity. Additionally, Sefton-Green (2013) found that school students were unable to give an agreed definition of what being digitally creative meant.

New technologies are accompanied by new opportunities for creative expression (Robinson, 2011), as well as technology linking young people to new ideas and artefacts from all over the world. The recent emergence of the "creative economy" links technology with "freedom self-expression, newness and innovation" (Sefton-Green & Brown, 2014, p. 27). Digital technologies do not stand still and any person's cultural education needs to ensure that the skills and knowledge learnt continue to be relevant to them and the world around them (Henley, 2012). Buckingham & Sefton-Green (2005) argue that digital technology might help to bridge the gap between consumers and producers "these new production technologies may begin to abolish distinctions between readers and writers" (p.213).

Hugill & Yang (2013, p. 16) recognise three different forms of creative computing:

- creative development of a computing product - how does someone act creatively when producing digital artefacts
- development of a creative computing product - how can computers exhibit creative attributes
- development of a computing environment to support creativity - how can computers support users in

being creative

I now explore each of these forms:

2.2.4.1 Creative development of a computing product The creative development of a computing product requires some form of *digital literacy*. There are several different, though similar definitions of digital literacy. These definitions include the ability to understand digital technologies and be able to share and create meaning with them (Hague, 2010) as well as social awareness, critical thinking and knowledge of digital tools (Newman, 2009). Importantly, being digitally literate is not just about using computational tools but knowing "when it is appropriate to do so" (Papert, 1980, p. 155).

Within computing literature the words "creativity" and "creative" are often used to represent any act of making, or a version of computing that has some form of artistic output. In Brenan, Chung and Hawson's (2011) *Creative computing: A design-based introduction to computational thinking*, they link creative computing to "young people's interests and values" , where they create "dynamic and interactive computational media" and state that "[m]any young people with access to computers participate as consumers, [...] [creative computing means they should be] designers or creators" (p.3). But often the word *creative* remains undefined, presuming the reader will be bringing their own definition. However, an element of making remains at the core (e.g. Garneli, Giannakos, & Chorianopoulos, 2015; Quinlan, 2015). Hugill & Yang (2013) describe the "poetic endeavour" (p.5) of how computing is done, outside the actual purpose of what is being made; that is, you can be creative in making something, without the product necessarily being useful in a creative way. With a focus on computer programming, they compare coding to creative acts involved with making music.

Csikszentmihalyi (2013) observes that creativity involves "surplus attention" (p.8). With teachers and students increasingly short of time and with creativity often needing a "long incubation period", creativity, digital or not, appears to be less likely in the classroom (Steers, 2013, pp. 168–169). Outside the classroom things might not be much better. Sefton-Green (2014) notes the difficulty in finding examples of out of school clubs that "genuinely combine creative and digital learning, or which focus specifically on coding and programming skills in relation to creative or artistic activities". Vygotsky (2004), writing many decades ago, recognised the technical nature of art suggesting that the two should be combined in any good education: "this merger of technical disciplines and exercise of creativity is, undoubtedly, the most valuable method in the educator's repertoire for students of this age" (p.85). Supporting this, introductory college courses in computing have been shown to be successful when incorporating art into computing. Greenberg, Kumar, & Xu (2012) found that a computing course "using generative art and creative coding" (p.1) was better at engaging students in computer programming than more traditional approaches. However, in the

UK, Sefton-Green (2014) notes that "the cross-disciplinary benefits of creative computing are not yet fully recognised".

Digital making in general appears to be seen as creative, where digital making defines some act of creation using digital devices, including the act of programming. Quinlan (2015) found that 56% of young people associated the word "creative" with digital making. Although it remains unclear what students understood by the term in this context, as it appears to be undefined. The most common forms of digital making undertaken by school children in the UK were: Digital Pictures (76% of students did this), Edited photos (76%), Edited videos or visual effects (62%), Animation (56%), Music (53%), Games (53%), Websites (53%), Software (52%) etc. (ibid. p.19). This supports the idea that creative, as in artistic, digital making projects are good ways to engage students with the most popular forms of digital making involving artistic expression. Unfortunately the research didn't differentiate on types of animation and visual effects.

"Creative computing" often has a narrower definition than Hugill & Yang (2013) argue, with computing used synonymously for "programming". For example, the MIT "Creative Computing" workshop[6] aims to "[enable] students to create interactive stories, games, animations, and simulations", all through the Scratch programming language. There is a similar course using Scratch, with a similar title running at Harvard[7]. In addition, the definition of computing appears to be contested, with the English national curriculum settling on a broader computing = computer science, information technology and digital literacy (DfE, 2013). Despite the dominance of artistic and apparently non programming forms of digital making amongst children, the most popular promoted activities for digital making in the UK were programming opportunities, with 3D printing being the only large activity that didn't implicitly have a programming component (Quinlan, 2015, p. 23).

Sefton-Green (2013) argues that whilst the term coding is mostly used to describe computer programming, it can also "express a translation of idea into a particular symbolic language and thus can imply greater generalisability" (p. 20). There are several examples of a more generalised application of 'code', Blades (2012) describes how they created a Choreographic Language Agent (CLA) which used symbolic language to describe dance. They go on to raise interesting questions about the relationship of the CLA to the art form, "can we really consider computer images, to be a dance work?" (p.225). Within the space of computing education, unplugged computing is a common way to teach computer science concepts. As the name suggests, no digital devices are used when teaching unplugged computing, and parallels can be drawn here with the conversion of ideas into symbolic languages that instruct people rather than machines. For example, Bell,

[6] http://cs4hs.media.mit.edu/
[7] http://scratched.gse.harvard.edu/guide/

Alexander, Freeman, & Grimley (2009) describe students creating name bracelets by encoding their names in a binary format using beads.

2.2.4.2 Computing environment to support creativity Increasing use of digital technology in schools has been matched by a scepticism amongst researchers and school staff as to the effectiveness of the new tools, and the ability of computing to support creativity in the classroom. Clements & Sarama (2003) present research that shows "drill and practice" software to have "little positive effect on creativity" (p.12), whilst other "knowledge creation" software does, though again, we might question the definition of creativity as it appears reasonable to assume that drill and practice might help people master the *domain* of any particular field (Csikszentmihalyi, 2013). There are also examples of schools using technology in unimaginative ways that mimic traditional media, e.g. using PowerPoint presentations like a textbook. Additionally, the fear of the freedom that technology brings to the classroom and the accompanying dangers has seen teachers and schools putting strict controls on how students engage with technology (Banaji, Cranmer, & Perrotta, 2013). The computing curriculum in England was introduced in 2014 to tackle the fact that previous digital technology education was considered uninspiring (Furber, 2012). However, the impact of the changes are still unclear in terms of making the subject more exciting.

Hugill & Yang (2013) describe how software can sometimes be a hindrance for creativity "[often] artists and people working in the humanities accept the unambiguous constraints of computer systems because they have the appearance of a neutral authority, of scientific 'fact' " (p.5), thus making a case for wider understanding of computer software, one that is both creative but also restrictive in terms of the invisible lines of force that it imposes on the user. They challenge software developers to make programs better suited to be a "servant of people by being more adaptive, smarter and better engineered to cope with frequent changes of direction, inconsistencies, irrelevancies, messiness and all the other vagaries that characterise the creative process" (ibid. p.5). It is essential to develop a computing environment that support creativity rather than limiting it. Failure to do so means that the creative potential of users will be compromised.

2.2.4.3 Creative computing products Mayer (1999) describes attempts to simulate human creativity by the development of a creative computing product that mimics human creativity. These systems might be described as "combinatorial creativity" - where programs iterate through multiple arrangements of a product's features until the best combination is found. The other model described is "exploratory-transformational [ET] creativity"; in this version of creative computing the underlying grammar of a task is mutable, it is not only the features of the artefact that change, but the underlying rules to create the product. For example, ET-creativity might iterate through ideas of different shoe types on a character (combinational creativity), but the model might also mutate the rules for where shoes appear on the character and how many legs the character has. Examples for ET creativity might be the development of genetic algorithms, where the execution and structure of code changes between iterations of a program. The iterative mutation here being the important part: "ET-creativity (unlike combinatorial creativity) involves not only the appearance of novelty, but also its development" (Boden, 1999, p. 367). Both models mimic human action by implementing the idea that creativity involves multiple ideas and a Darwinian approach to the selection of what is important (e.g. Richards, 2010).

It should be noted that both combinatorial and ET creativity tend to focus on the person and domain elements of the systems model of creativity, largely ignoring the field (Csikszentmihalyi, 2013). Boden (1999) describes how the full creative process cannot be contained within a computer program "creativity is not a purely scientific concept, since a creative idea (by definition) must be valuable in some way, and values cannot be justified by science" (p.351). Human interaction with creative computing appears to be essential, both in terms of situating the research in the wider domain and engaging with the wider field for recognition of the research. As such, creative computing products can be seen as part of the wider research area of digital creativity, albeit remaining as a tool for humans to use.

The inclusion of human beings in verifying and validating the creative outputs of machines is taken further by Leavis (1972) who argues that: "responsibility must, of its nature, *be* human" (p137). When told that a computer had written a poem he replied that "it was one of the things that I *knew* to be impossible" (ibid. p.142). Whilst we can use computers as tools in helping us become creative, they themselves can never possess the responsibility involved in actually being creative, that can only come through human beings. As such, computers will remain tools, so we cannot ignore the social circumstances in which they are used, let alone pretend that we can use them without some form of social verification and validation.

2.2.4.4 The difference of digital creativity Sefton-Green (2013) argues that as society becomes more engaged with digital technologies, it increasingly needs ordinary people to become digitally creative. By doing so we can sustain a critical and democratic society. Debates around the implementation of digital education have seen tensions between different interpretations of digital creativity, including digital culture, CS and the social uses of technology. Within the English education system computing is defined as being a combination of computer science, digital creativity and information technology; however, the government has narrowed the subject space at GCSE, introducing computer science but removing the ICT qualification (DfE, 2015b). Recent government investment in teacher training has focused on computer science (STEM Learning, 2018) and Sefton-Green (2013) notes that "it is rare to find common principles of digital creativity across the subjects in the English School curriculum" (p.26). He goes on to argue for the positioning of digital creativity "as an integrated concept across, as part of and as discrete from other creative production disciplines" (ibid. p60). He goes on to outline four dimensions that make digital creativity different from other forms of creativity:

First, the digital medium implies the use of specific skill sets and outlooks including computational thinking, often expressed through coding which would not be required in other forms of creativity. Wing (2008) argues that computational thinking can transfer into other domains, which would imply that this specific digital skill set might be equally applicable in other areas of creativity. Whilst there are clear examples of the generalisability of coding concepts in areas of creativity, e.g. using algorithms to create art or create music (e.g. Barr & Stephenson, 2011), Denning & Tedre (2019) argue that computational thinking focuses on the creation of computational automations that live in computer hardware, supporting Sefton-Green (2013) in the specificity of computational thinking and code (and the interaction between them) to digital creativity. It should be noted that subjects such as media studies make use of digital technology as part of the course, but do not make explicit links to computational thinking or coding (e.g. OCR, 2018), though computational thinking concepts might be present, e.g. automation of certain processes. The question here is whether creating using digital products without coding and explicit links to computational thinking can be considered digitally creative.

Second, the difficulty in separating digital creativity from the domain of the product that is being created, which comes with its own rules and expectations. For example, if we were using digital tools to take photographs, our photography would still be within the knowledge *domain* of photography, with the artistic rule of thirds, exposure, etc. The separation of tool usage (and creativity in such tool usage) from the artwork becomes increasingly difficult, especially as more media production moves across to digital form (Manovich, 2013). This leads to difficulties in the assessment of digital technologies: "Do we evaluate students' grasp of authoring packages or their capacity to *imagine* in the new medium?" (Sefton-Green, 1999, p. 149).

Third, digital often encompasses sharing and communication with others, these both impact the design and the output of the artefact. This ongoing interaction with the *field* is also recognised in the computing pedagogy of constructionism (Papert & Harel, 1991), where makers will be producing a digital artefact for a public audience. In addition, successful digital makers have been able to relate their work to employment and learning communities, making the work they did real with a "clear form and purpose" (Sefton-Green, 2013, p. 13). Young people interact with digital technologies on a continuum that includes social, recreational and constructive modes of engagement (ibid.). Ito et al. (2009) describe how digital creation has moved beyond the boundaries of formal education into non-formal clubs and support networks. But this should be tempered by the findings of Sefton-Green & Brown (2014), who note that mentors, often teachers for students from working class backgrounds, are not easily available for everyone. Sefton-Green & Brown (2014) also found that there were students who were digitally creative but isolated from extra-curricular activities who were then unable to situate their learning in terms of potential careers.

Fourth, learning has been transformed by access to online environments, offering both access to learning materials and learning communities from all over the world. Self-teaching is seen as incredibly important as a skill that is needed to survive in a constantly changing job market. Whilst most students might be using the internet, their usage of the internet varies widely (Ofcom, 2017). Online environments are clearly important for digital creativity, but we cannot escape the differences in usage experiences by students from varying socio-economic, cultural, educational and gender backgrounds.

It remains to be seen how the dimensions, explained above, manifest themselves through the creation of 3D digital artefacts and how 3D digital creation differs from other forms of digital creativity. For digital creativity to occur must all the components be included and what impact does the focus on one or more component have on the overall creative experience. For example students creating 3D animations might not produce any code at all, how does this impact their *digital* creativity?

2.3 Summary

This chapter covered the key concepts, theories and pathways behind creative digital making, with a particular focus on creative digital making in England. To help understand the role of 3D animation in supporting the development of digital creativity, I first explored the subject areas related to 3D animation, and then outlined concepts of creativity, specifically, digital creativity.

The chapter outlines some of the rationale behind recent computing curriculum changes (e.g. Gove, 2012), arguing that broader interpretations of digital creativity beyond computer programming are needed. It finds that recent changes in the curriculum see a massive under representation of females in computer science qualifications (e.g. Royal Society, 2017). A broader interpretation of Science, Technology, Engineering and Mathematics (STEM) education is needed and the inclusion of arts into this mix can help engage females with technology, including computing (e.g. Catterall, 2017). Whilst media studies and computer science can both be considered to be part of the domain of digital creativity, the cohorts taking them show very different profiles and grades, suggesting that a more inclusive approach to digital creativity could be achieved by combining areas from both subjects. Arts education in England appears to be in decline (Steers, 2014), and the myth of the digital native is a dangerous one (e.g. Selwyn, 2009). Without a formal education in subjects related to digital creativity, many students, particularly those from poorer backgrounds, will not have access to the skills and knowledge to become competent, creative and critical users of technology.

Creativity is a contested term (e.g. Banaji et al., 2010), with digital creativity often used but seldom defined. After looking at multiple definitions of creativity I settled on using Csikszentmihalyi's (2013) systems model of creativity, further exploring his concepts of the domain, field and person and linking this model to Bourdieu's (1986) theory of capital and other theories of creativity. Looking specifically at digital creativity, I outlined Hugill andYang's (2013) definitions of creative computing products, creative computing environments and the creative development of a computing product, connecting them with other models of creativity, including the systems model. Finally, I examined Sefton-Green's (2013) four dimensions of digital creativity, making links between this model, the national curriculum in England and other models of creativity. I ended the chapter by asking how does 3D animation manifest itself as a form of digital creativity. This is explored below.

3 3D animation, semiotics and computational thinking

This chapter will look at the theories that underpin the development of 3D animations, these include: media literacy, semiotics, multimodality, digital literacy and computational thinking. I study how 3D digital animation fits into these theories and also argue through these theories that 3D animation is different from more traditional modes of digital creativity in schools.

First, I outline the argument for why 3D animation is an important subject for students to study. I outline the *powerful knowledge* (Young, 2007) and economic arguments(e.g. Djumalieva & Sleeman, 2018), I contend that similar arguments made about the importance of studying media and computer science can also be applied to 3D animation, that the study of 3D animation will help students in becoming critical members of society, as well as provide them with skills that are currently needed by the economy. I outline current research around digital art in educational settings, highlighting the lack of research around non-programming based initiatives, the lack of research at secondary school level, and the focus on media literacy and lack of computing theory seen in machinima[8] research. Noting the gaps in the research I argue that there is a need to study 3D animation for secondary students, through the lenses of media, which I will go on to define as multimodality, and computing theory.

Second, I outline media literacy looking at the ability to read, write and critique in a medium (e.g. Buckingham, 2003). I argue that 3D animation is an example of a media text. I focus on multimodality theory using Kress and van Leeuwen's (2001) concepts of discourse, design, production and distribution, outlining each and linking in other theorists where possible. Looking more closely at the factors that impact design decisions, I argue that the literature fails to cover the interaction between software and hardware in influencing what can be made. This is an essential component of 3D animation and this relationship has a direct influence on what can be made and therefore what is likely to be designed. In addition, I argue that in team based projects, the understanding of other team member skill sets will influence what a designer deems appropriate to be made. With a focus on Burn's (2013) *kineikonic chronotope* I argue that the order of development for contributory and orchestrating modes for the described machinima project can be more fluid than presented; with software, in particular 3D animation software, allowing for the development and remixing of signifying modes at almost any stage of development.

Third, I outline computational thinking focusing on the elements of abstraction, decomposition, algorithm, evaluation and generalization, as outlined by Selby & Woollard (2013). In addition, I argue for the importance of automation in digital making and make the case for the broader understanding of computational thinking,

[8] machinima is the creation of films using real time graphics such as those found in computer games

where it can be studied in domains outside computer science. I cover the brief literature on 3D animation and computational thinking, noting the theoretical and underdeveloped nature of the work (e.g. Kemp, 2014a).

Fourth, I look at the impact of software choice on media creation, as suggested by Sefton-Green (2005). I outline how media making tools have largely been reduced to computing allowing for deep remixability and modularisation of work (e.g. Manovich, 2013). I cover the arguments surrounding the choice of software arguing for the democratic nature of open source software (Perens & others, 1999) to be taken into consideration along with the features available through the software. I then look at software in terms of the affordances the technology offers the user (e.g. McGrenere & Ho, 2000), what possible things can be developed through a software tool? I coin the terms *internal* and *external* expression as a way of understanding the things that a tool can represent inside a program and as a finished product, and theorise about tools being *expression complete*, where a piece of software could represent any artistic output. Lastly, I outline the argument for creating authentic environments for student learning (e.g. Burn, 2014), and therefore using authentic tools, such as Blender, in student media creation, whilst admitting that other software might be more suitable for other purposes.

3.1 Why 3D digital animation

Three of the most pervasive forms of multimedia amongst children are computer games, websites and films/animations/TV shows (Ofcom, 2017), each of them often produced with special effects and 3D digital technologies. The new computing curriculum has gone some way in demystifying the programming aspects of computer games and webpages through its teaching of programming (DfE, 2013; Livingstone & Hope, 2011). Film/animation/tv production techniques are covered by Media curricula (e.g. OCR, 2018), but the 3D technologies used to create everything from the latest Hollywood films to day-to-day children's TV animation and computer games are largely absent from the mainstream curriculum, outside a few specialist courses[9]. Society largely positions children as consumers of media rather than creators; even where a media organisation such as Nickelodeon claim to represent children's interests "this discourse does not define children as independent social or political actors" (Buckingham, 2003, p. 31). The absence of a basic literacy in this area creates a relationship between these sort of media and the child, one of master and potential slave (Buckingham, 2003, pp. 18–20).

Buckingham mentions that initiatives around media education need to prove that they are providing employability skills in order to get funding (2003, p. 198), and recent changes to the computing curriculum have been linked explicitly to the idea of jobs and the economy (e.g. Gove, 2012; Furber, 2012). The creative

[9] e.g. The NextGen Skills Academy https://www.nextgenskillsacademy.com/

industries in the UK currently has skills shortages in areas such as 3D animation (MAC, 2015) with skills related to digital art and 3D digital animation expected to be in great demand in the near future (Djumalieva & Sleeman, 2018). 3D digital animation is an area of growth in industry (Djumalieva & Sleeman, 2018) and that growth will likely be accompanied by increased consumption. The need for students to better critique and create 3D digital animations will not only open up routes for employment, but allow students to better understand and shape the world around them.

I understand education to mean more than fuel for business; one of the aims of education is to democratise culture. This means that computing and media education should aim to give children the tools and the skills to demystify and create the most common forms of media they consume. And this involves teaching the relevant concepts and skills, as well as placing the tools of creation into the hands of children. I argue that to do this for 3D animation spans two subject areas, media studies and computing; the language of media production and the language of computer usage need to be taught together. Therefore it is important to look at key theoretical areas involved in both subjects, namely media literacy, film semiotics, multimodality, digital literacy and computational thinking.

The question now falls on why I have chosen to focus on 3D animation and not some other area of digital creativity.

Young (2007) argues that schools are there to deliver 'powerful knowledge', that is specialist knowledge that we cannot expect students to gain easily from their own families and communities. Robinson supports this "One of the roles of education is to broaden and stretch the interests of students, into areas for which they may not have a natural affinity" (Robinson, 2011, p. 250). Powerful knowledge "provides more reliable explanations and new ways of thinking about the world and …can provide learners with a language for engaging in political, moral, and other kinds of debates" (Young, 2008, p. 14). Computer science can be considered powerful knowledge (Webb et al., 2017) as it is used to construct much of the world around us. Our possession of it allows us to understand, change and critique the nature of the world. The teaching of computing might allow a student to understand how some of the algorithms behind *Google* search work. This will allow them to read the results from the search engine more critically, understanding that the results are not an objective picture of the contents of the world wide web, but influenced by a corporate agenda to help sell products and services. Taking this example further, giving students an understanding of computer science will allow them to critically engage with Google search results by using, imagining or potentially building an alternative system. Other elements of the computing curriculum can also be seen in the light of powerful knowledge; as mentioned above, staying safe online isn't knowledge readily available to all students, understanding how encryption works and the arguments around data protection laws opens up debates into digital rights and the power of the state.

Buckingham & Sefton-Green (2005) argue that technological change may bring about democratic change "new production technologies may begin to abolish distinctions between readers and writers or between consumers and producers", even "blurring the division between 'amateur' and professional production" (p.213). This mirrors arguments elsewhere for teaching programming: "these kids were able to program the computer, rather than let the computer program them" (Harel, 2001). Clearly there is an importance in teaching students to be creative and critical users of the technologies which they consume. Teaching students how to make 3D animations will demystify the construction of games, television, adverts and film, helping students understand how the world around them has been created. This will make them less susceptible to the power of media messages and allow them to engage with political and moral debates around media, as creators and as people who can critique. 3D animation in particular is *powerful knowledge*, as other forms of digital making such a digital photography are much more democratised. For example, students can create their own photos using everyday mobile phones. There is currently very little opportunity for students to learn 3D animation in formal and informal settings.

Another argument for teaching something in school is the economic benefit to both the country and to the students. Changes in the curriculum, which introduced computing instead of ICT were based on such reasoning, with a focus on the need for computer science (e.g. Gove, 2012; Furber, 2012). Reports lamenting the state of digital education continue to be produced (Edge, 2008) and the UK Government occupation shortage lists show digital skills as amongst the most needed for the economy (MAC, 2015). From this it follows that we should teach what will give our students the best opportunity for future employment and therefore increase their life chances, and in this case the focus should be on subjects such as computer science. However, computer science and programming in particular are not the only digital skills that are in short supply (MAC, 2015); most recently a Nesta report (Djumalieva & Sleeman, 2018) lists animation and multimedia as the most promising digital skills for the future workplace, yet, the curriculum change has resulted in animation and multimedia skills, once common in ICT, no longer being part of computing exams. Additionally Rudd (2013) questions the involvement of business in shaping curriculum reform and whether the focus on computer science was the best focus for children in schools. Manovich (2013) assumes that "the number of people who work in media and who can also program is tiny in comparison to the army of application users" (p.31), indicating that a broad range of digital skills will be useful for anyone wanting to get a job.

Some attempts have been made to study the use of 3D digital animation in a school environment, but so far the studies have been looking at 3D animation from a Media studies (in particular machinima) perspective, theoretical, focusing more on teaching coding than animation, limited in scope, or based in universities. A gap in the literature exists around secondary school aged students making 3D animation using industry tools. I will now cover the existing literature on 3D animation creation.

Aoki et al's. (2017) university study talks about the importance of teaching how the pipeline works in any 3D animation formal education, also stressing the importance of working in teams. Building on this work Joel et al. (2018) set up an online collaborative environment for students in different universities to work together, recognising that animation/visual effects is a highly collaborative environment, and that students might struggle to work in large teams if they themselves were in smaller university cohorts. Roller (2015) attempted to find consensus about a knowledge base for computer graphics, and whilst it might be argued that computer graphics is a broader area of research than 3D digital animation, they found that "core CG [computer graphics] knowledge base must include art and design, animation, digital imaging, physics, visual perception, visual communications, mathematics, cognitive sciences (psychology), and computer programming" (ibid. p102). A study (Aoki & Koning, 2011) of US university 3D animation schools found that 14% of 3D animation sat within the engineering / information science departments, 50% within art and/or design and 22% within film/video/animation. A third of courses had computer programming as a requirement and software and hardware were seen as the major financial burdens on institutions.

When looking specifically at the use of 3D digital animation in the classroom there is limited research beyond the lens of Media studies and the use of consumer level software tools such as those used to create machinima (see Media theory and literacy, below, and Burn & Kress, 2018; Burn, 2013). Focused on computing, Lin et al. (2017) have studied the process of students customising their own 3D characters, arguing that giving student the ability to customise the assets that they use in making is an important factor in engaging students in their learning and Jörg et al. (2014) found that 3D digital animation could be used as an effective way to engage children with computing concepts.

Many people have already explored the link between digital art and computational thinking (e.g. Resnick et al., 2009; Orr, 2009; Rim & Lee, 2012), however, the work is mostly in the form of expressing programming through digital art, using the Scratch and Alice programming environments and the processing language. Perković, Settle, Hwang, & Jones (2010) made an attempt to fit animation and 3D modelling into a computational thinking curriculum, though the exposition of these topics is limited i.e. "Techniques such as abstraction, modularization, automation, and randomization are necessary to create realistic models that can be efficiently designed and processed" (ibid. p127). My own preliminary research into student learning of 3D animation (Kemp, 2014a) notes that similar computational thinking skills are being learnt through the creation of 3D animations as are learnt through programming and computer science (CS). My work argues that some elements of computational thinking, e.g. modular design, are more accessible to beginner 3D animators than to beginner programmers. However, my work is largely theoretical and lacks data to support my assertions. I also note here that there is no pedagogical literature on how to teach 3D animation.

In conclusion, I argue for a broader understanding of computing that includes 3D animation, with computing and media skills involved in 3D animation being important for children in terms of their engagement, understanding and critique of the world around them. There is currently very little research into 3D animation in schools that links to computing skills, or goes beyond the use of consumer level tools such as machinima. There are preliminary studies linking 3D animation to computational thinking but they lack data. This thesis aims to address this dearth of research by providing evidence on how school children use media and computing theory in their development of 3D animations.

3.2 Media theory and literacy

3D digital animations can be seen as prime examples of media texts, as defined by Buckingham (2003); as they combine multiple forms of communication, with sound and moving images coming together to make the finished artefact. In this sense 3D digital animation fits perfectly into an area of research encompassed by definitions of media literacy and media studies.

A popular understanding of the purpose of studying media is that a student is better prepared to understand, critique and participate in the creation of the media messages that surround them (Buckingham, 2003, p. 7). By being able to critically analyse media artefacts and by understanding how such artefacts are made, one becomes less susceptible to the influence and power of messages contained in these artefacts. Children are surrounded by multimedia and throughout the last hundred years we have seen technology giving children greater access to the tools that create their entertainment, democratising access to media production (Manovich, Malina, & Cubitt, 2001). Burn & Durran (2007) refer to technology as providing " 'democratic' tools" (p.137) for students; no longer are students just consumers of media, they are also able to make media themselves. There are many examples of a movement from consumer to creator: reading of books and the development of typewriters and word processors; the viewing of photographs and the development of consumer cameras and cameras attached to mobile phones; the reading of newspapers/magazines/posters and the development of desktop publishing software; the viewing of television shows/ film and the development of portable video cameras including phone cameras and film editing software; the viewing of animations and the development of cheap stop motion cameras and 2D animation packages; the viewing of 3D animation and playing of games and the development of machinima (e.g. Burn, 2016; Manovich, 2013). As I will argue below, we need to see this transformation not just in terms of being able to create in a medium, but in terms of what we are able to create. If consumer cameras were only able to take black and white images compared to the colour images of the professional, we might argue that photography was far from being democratised. The same argument can be applied to the consumer level tools available for 3D creation such as machinima: can we say that machinima has truly democratised 3D media creation if the outputs are not fully comparable to the professional level creations? E.g. I can create iterations of a Western Movie in machinima because that is what the software allows, but never a Hittite epic.

Kay (1990) defines literacy in any medium as both reading - the ability to "access materials and tools generated by others", and writing - the ability to "generate materials and tools for others". Stating that "You must have both to be literate" (p.125). Media literacy involves reading and writing media artefacts, including 3D animations. Buckingham's (2003) definition of media literacy goes beyond Kay, stating that it is a form of critical literacy:

> It involves analysis, evaluation and critical reflection. It entails the acquisition of a 'metalanguage' - that is, a means of describing the forms and structures of different modes of communication; and it involves a broader understanding of the social, economic and institutional contexts of communication, and how these affect people's experiences and practices. (p.38)

There are parallels here with the idea behind digital literacy where those that are literate are able to be critical and creative in their use of technology and media (Hague, 2010). Just acquiring a knowledge of theories behind media creation is not enough and both digital and media literacy stress the importance of mastering digital tools through production (Buckingham, 2003; Newman, 2009).

Within media literacy, Burn & Durran (2007) describe a range of different literacies, including television and cine-literacy. Though much of the textual analysis skills from 2D animation will map to 3D digital animation (e.g. Lasseter, 1987), many of the practical skills required will differ. An outline of these skills is attempted in curriculum and pedagogy below.

Buckingham (2003) outlines four key concepts to media education, presented in Table 3.1: Production, Languages, Representations and Audiences and argues that they all interrelate.

Table 3.1: four key concepts to media education (Buckingham, 2003)

Component	Summary
Production	Production process, the broadcasters and sponsors, cross-media marketing, global sales

Component	Summary
Languages	Editing, visual style, the generic mix of genre
Representations	‘realism’ and falsehood, performance, the construction of characters, moral values
Audiences	ratings, newspaper reviews, ‘interactive TV’, audience response

In a similar vein, Kress and van Leeuwen’s (2001) *multimodality theory* looks at how students create meaning through multimedia. I cover this in the next section.

3.3 Meaning making

Films engage the viewer through their use of already understood systems that create the film’s form. For example, the use of flashbacks to give a backstory, or the use of close up shots to help portray emotion in a character. Different genres have different conventions: a quick cut between shots might help signify an action movie, or sets with bright colours might help establish a children’s film. No one system can be used in isolation and we cannot separate the impact of conventions from one another. For example, bright colours mixed with sinister music might help create a horror movie rather than a children’s movie. The choice of conventions by a filmmaker must also be made in recognition of the understanding of the audience, who will attach *meaning* to what they see on the screen based on their prior experiences and prejudices; through similarity, repetition, difference and variation, messages for an audience can be created (Bordwell & Thompson, 2010). In this section I will look at meaning making in film through the use of semiotics, multimodality and the kineikonic mode.

One way of understanding the meaning attributed to film, and multimedia, is through the concept of semiotics. Semiotics outlines the relationship between a *sign*, an *object* and an *interpretant*. The sign being something of substance, e.g. words, images, sounds; an object being the thing that is being signified, e.g. a sign of a red piece of card, signifies the object of danger; and the interpretant being the understanding we have the relationship between the sign and the object, e.g. I might understand the red sign to mean danger, someone else might understand it to mean warmth (Atkin, 2013).

Theorists have attempted to apply semiotics to multimedia, artefacts that combine one or more media forms. Kress and van Leeuwen’s (2001) *multimodality theory* aims to provide a framework through which we can understand the creation of meaning across multimedia artefacts including film and 3D animation. Kress (2009) describes modes as “socially and culturally shaped resource[s] for making meaning” (p.79), listing as examples "image, writing, layout, gesture, speech, moving image, soundtrack and 3D objects". The social context of a mode is important here as cultural factors influence understanding, and semiotic modes must be used in a "recognisably stable way" (ibid. p.25) to convey meaning, one that is always imbued with the history of how that signifier has been used previously within a society (Burn & Kress, 2018). For example, the word *Jihad*, when used in a western European Christian setting might illicit ideas of terrorism, whilst the same word used in a Muslim setting might bring about an understanding of an individual's struggle to purify their soul. The use of a muscle car driving into a shot might signify power and wealth for some, whilst for others it might signify arrogance and disregard for the environment. We can select different modes to express the same meaning, or to reinforce the meaning of something (Kress & Van Leeuwen, 2001). For example, a scene where two lovers meet might contain romantic music which is complemented by a warm pinkish tinge to the lighting and a lot of roses.

As seen above, expression of meaning can take on many forms, with some forms being better than others at describing certain things (Kress & Van Leeuwen, 2006, 2001). For example, the use of music might create a majestic atmosphere better than the use of lighting. It might also be argued that some meanings might be impossible in some modes, taking the 'Mary's room' experiment of Jackson (1982) as an example of this. Mary is in a room whose only outlet on the external world is through a black and white television screen. She can learn anything she likes about the world, including how light works and how colours are made. It is argued that on leaving the room and experiencing colour through her eyes in the external world, rather than through her understanding of colour, Mary would learn something new. The same argument can be made here with modes, can one mode express something that other modes cannot? Can music, or images, or the feel of something express meaning in a way that is unavailable in other modes? Kress & Van Leeuwen (2001) argue that different modes have different effects, some modes might be better for production/instruction, others better for interpretation.

Multimodality is opposed to monomodality, the communication through one mode (Kress, 2009). For example, we might consider that text is a single mode, but when we look at it further we cannot escape the impact of the font that the text has been written in, the colour of the ink or the texture of the paper it was written on. Text saying "I love you" might mean something very different if written by hand or typed in comic-sans font. This multidimensionality of any mode means that the pure monomodal form seems unlikely to exist.

Multimodality makes us consider the different modes of film production, not separate from each other, but as a web of interactions and double meanings. It argues that modes do not act independently of each other (Kress, 2009). Bordwell & Thompson (2010) also state that the viewer doesn't allow for modes to be expressed separately and that “our minds seek to tie these systems to one another” (p.57). Tarkovsky (1989) goes further, arguing that a film, as an artwork, is indivisible and that “No one component of a film can have any meaning in isolation” (p.114). This creates the fear that an attempt to look at multimedia works by dissecting them into their component parts might miss the bigger picture; but we must also recognise that our focus here is on school children who are learning the language and grammar of film production. Tarkovsky also writes that “in order to write well you have to forget the grammar” (p.88), it follows that first we must learn the grammar of film, and the use of this grammar can be analysed.

Kress and van Leeuwen’s (2001) propose four components to multimodality, discourse, design, production and distribution. They stress that all four interact with each other and the distinctions between the components, as I show, can become blurred.

3.3.1 Discourse

A discourse is a socially constructed knowledge of some form of reality (Kress & Van Leeuwen, 2001). According to Weedon (1987) discourses involve the interaction of “knowledge, together with the social practices, forms of subjectivity and power relations” (p.105). Kress (2009) outlines how discourses allow a society to make sense of its world, providing them with the resources to build an “epistemological coherence” (p.110) in semiotic resources. Examples might be sexist discourses, racist discourses or religious discourses; discourses generally point to “phenomena which are easily recognized and difficult to describe” (ibid. p.114).

Modes serve as relatively well understood ways of carrying out a discourse or expressing a genre. Discourse is different from genre, which has a more stable shared understanding of meaning and interaction. For example, a western movie might be set in the desert, and have good guys and bad guys, sheriffs, cowboys and Indians; a discourse on gender struggles to provide such easily identifiable and understandable modes. Discourse “offers meanings to be realized” (Kress, 2009, p. 114), it ask questions and it seeks exploration. Whilst the rules of a genre might be relatively well understood, a discourse interacts with itself. By engaging with a discourse we might start to change the meaning of the modes we have used, as well as our understanding of this discourse and other related discourses (Kress & Van Leeuwen, 2001). An attempt at genre is far more likely to elicit in a creator the sense of success or failure in meeting the criteria of that genre. The success of a discourse is less well defined, where meaning might be conveyed by modes more suited for other discourses (thus expanding the discourse), or attempts to use modes in unrecognised ways, which might lead to confusion.

The creation of a media artefact leads to the questions: “In what modes, in what discourse(s), in what genres should we present meaning” (Kress, 2009, p. 121). Decisions on the choice of mode, discourse and genre might be conscious or unconscious, the choice of modes impacts the discourse which impacts the genre, and vice versa. It is through discourse analysis that we can understand the multifaceted nature of choices made by students when making films. But it should be noted that “articulation and interpretation are not necessarily combined in one person in relation to a particular mode or set of modes” (Kress & Van Leeuwen, 2001, p. p41), meaning that students might not be able to understand the discourse that they have created. Alongside writing, video games and films are seen as places where discourses can take on a material form.

3.3.2 Design

Design is a “deliberateness about choosing the modes of representation, and the framing for that representation” (Kress & Van Leeuwen, 2001, p. 45). Design describes the modes that are used by a creator to express intended meanings. Design must take into consideration the audience that the artefact is being designed for, as the audience will bring their own understanding of meaning to the final product and a lack of agreed understanding on the meaning of modes may lead to vastly different interpretations (Kress, 2009). The semiotic ‘potential’ of any particular mode can be “defined by the semiotic resources available to a specific individual in a specific social context” (Kress & Van Leeuwen, 2006, p. 9), and communication is the maximising of shared understanding of a given mode. The use of modes might come naturally to the designer, maybe because they have a shared understanding of meaning with the intended audience, or modes might be heavily influenced by the education of the designer, e.g. through a school curriculum.

Burn & Kress (2018) describe three aspects that impact the design of children’s machinima “[student signifiers] are partly drawn from the *cultural experience* of the children [including education], partly from the *material assets* provided by the technology, and partly from the *physical resources* of their own bodies” (p.7; emphasis mine). It is clear that students cannot design from nothing and will always be influenced by their cultural experience, influenced by the background knowledge of modes available to the student and the curriculum or the expertise of an advising teacher. A student, when presented with a character model of Pharaoh Akhenaten, might not be aware of the historical significance of this character, and thus not understand the meaning that such a character would bring to people versed in the history of monotheism. Other limitations include the immediate surroundings and the tools available to a creator, that is the limitations of the production environment. For example, the computer tools that are being used to create characters might not have a template for an elephant and the story might have to be designed entirely with humanoid characters in mind. Another limitation that might be placed on the design would be the available time at hand, or maybe the production stage of the project would only allow for one set to be made. The interface of multimedia development software can influence the semiotic tools available to the user, through its use of toolboxes, opening up new possibilities of action and meaning (Manovich, 2013). But also limiting the user, through the design of the user interface, where invisible lines of force persuade the user to pick one mode of expression over another through the placement of tools (Kress, 2009). However, the interaction between software, hardware and peers is not expanded on in the literature. Whilst a piece of software might be capable of creating any artistic expression, the actual design decisions will result from an interaction between the software and how it runs on the hardware it is installed upon; for a team situation, the choice of design will also depend on recognised capabilities of other members of the team.

3.3.3 Production

Production describes the process of putting a design into action. In the context of 3D animation this might be creating models from sketches, and animating scenes based on a storyboard. However, production is rarely as easy as following a set of plans, issues with a design might be discovered, and the design itself might change during the process of production; “a blueprint is not a house” (Kress & Van Leeuwen, 2001, p. 51). Additionally, people involved with production often have the ability to add their own meaning to the designs they have been given. For example, a design might tell someone to animate a character walking from one location to another, the gait of the character might be left to the animator.

Design and production might be more intimately linked. For example, modern film making uses *pre-vis* shots, where film shots are mocked up, sometimes in the same software that will be used for the final shots. Pre-vis gives the director a feel of what will happen in the film . These mocked-up designs can be modified into final products, or remade in other software. For 3D modelling a design might evolve into a finished product, finished in the same tool where it was first imagined. This design and production might even take place on the same platform where the final product will be displayed[10] with lines between design, production and distribution becoming blurred. Within software development, the traditional model of design then production has started to be questioned, with the Agile Manifesto (Beck et al., 2001) arguing for collaboration over contracts, interactions over processes and accepting change over following plans. This model equips the production part of development with far more creative freedom than a design then process model would suggest.

3.3.4 Distribution

Media products need to be taken to the audience for meaning to be created as “communication only happens when someone interprets” (Kress & Van Leeuwen, 2001, p. 8). This involves some form of transmission and it

[10]for example: https://www.tinkercad.com/

might involve some form of re-coding. According to Kress & Van Leeuwen (2001) "re-coding always involves reduction" (p.89), for example, a 3D film whose makers see each shot in 3D dimensions, with the ability to 'fly' around the scene and add and edit cameras will be 'flattened' into a series of 2 dimensional frames, that will be stuck together to form a moving image.

Semiotic meaning changes depending on where and when the artefact is shown, or how many times it is shown and who it is shown to. Through interaction with an artefact the discourse it tries to represent might change, as might the meanings attached to the modes that are being used. For example, in the *Super Mario Bros.* computer game *Princess Toadstool* was there to be rescued; in *Super Mario Bros. 2*, *Princess Peach* was a playable character who could complete levels and solve problems just like the male characters; this called into question existing discourse on the gender within computer games.

The distributed medium is the message, and any flaws or changes in from the original message now become part of the new message. For example, the grainy artefacts on an old film help the viewer understand that the film is old (Kress & Van Leeuwen, 2001). Distribution does not always have to include a reduction in detail, re-coding might not be necessary: you can look at the code behind a website that you visit, potentially seeing all elements of production as well as the finished website. Nor does distribution need to include any changes in the original message, digital transmissions of data are normally faultless. Recently there have been 'open source' film productions where the final film is released along with the raw film production files; in these cases distribution is achieved with a re-coded and reduced data 2D film, alongside the original film data.[11]

Any distribution needs to recognise the audience. Tarkovsky (1989) states that "a book read by a thousand different people is a thousand different books." (p.177). It is the same for any semiotic work, where the creator of the work needs to make sure that their discourse and use of modes matches the understanding of the people who will watch it (Kress, 2009). Burn & Durran (2007) and Buckingham (2003) stress the importance of having a real audience when getting students to design media artefacts. This has parallels with Papert's (1991) constructionism, which theorises that the best learning occurs when students are actively involved with making a public entity, i.e. one that has an audience.

Buckingham (2003) writes about Goodman's video-maker project, where students described their work in progress to a range of adults and other peers, their potential audience. This ongoing discussion bridges the gap between discourse design, production and distribution, and as mentioned the four areas of multimodal discourse often interact and merge (Kress & Van Leeuwen, 2001).

[11] e.g. https://www.blender.org/about/projects/

I now turn to the *kineikonic chronotope* which looks at how space and time combine in the making of the moving image.

3.3.5 The kineikonic chronotope

Films are not just a collection of images or static modes, space *and* time and the situation of modes within both of these are important in conveying meaning. Bakhtin's (1981) chronotope argues for the inseparability of meaning from the temporal and physical location in which a message is conveyed. Tarkovsky (1989) describes film making as "sculpting in time" where the film maker takes a " 'lump of time' [...] cuts off and discards whatever he does not need, leaving only what is to be an element of the finished film" (pp.63-4). Bordwell & Thompson (2010) look at the use of position in film, be it the positioning of actors, props or the camera to convey meaning. They also cover the use of timing through methods such as shot length and montage.

Burn & Parker (2003) bring together the importance of time and space in film making with their *kineikonic* mode. This theory looks at how meaning in film is created through the combinations of multiple systems of significance, including images, music and speech. Expanding on this theory, Burn (2013) looks at two types of mode, *contributory* and *orchestrating*. Contributory modes include choice of lighting, costume and props and the orchestrating modes organise the contributory modes in time and space. For example, if students were making a film about a running race, they might pick contributory modes in the form of gym outfits, head bands, female actors, a running track set and exciting music; orchestrating modes would then be the location and movement of the camera within the set, allowing it to follow the runners, the actual filming of the shots, and the final cut and edit to put all the shots in the right sequence to achieve the intended impact. Within a film frame spatial decisions dominate the semiotic process, within the gathering of frames together to form a film through a timeline "the logic of the temporal appears to dominate" (ibid. p.4).

Burn (2013) describes filming as "resembl[ing] more the fluidity of speech; editing the fixity of writing" (p.5); however, he notes that some digital animation removes the physical action of filming, placing it into the editing process. In digital animation such as machinima, the sets and actions of a film exist in software, allowing the camera position, focus etc. to be changed at any point to achieve different effects. Thus the linear nature of the filming process becomes highly remixable and the relationship between the linear acquisition of Tarkovsky's (1989, pp. 63–4) "lumps of time" and the editing process becomes blurred.

In Burn's (2013) machinima work, he notes that contributory modes are designed before orchestrating modes; for example characters, sets and music might be chosen before the editing process. But it is unclear as to why this always has to be the case. For example, we could easily imagine a 3D digital film where the design of a minor character might be delayed (or even sent to be designed by another filmmaker) and included only once the first run through of a shot had been made. We might even abrogate the inclusion of background scenery until the animation of a character, the sound, the lighting and the speech had been completed; that is the shot could be complete in every way except for a minor contributory mode. Burn (2013) uses the term *lamination* to describe the creation of meaning through the layering and thickening of signifiers, the modes that make up the film, making clear links here between the lamination process of machinima students and more traditional forms of media creation. However, there is an important development here in the fixity of the act of lamination in traditional media. As described above, decisions around contributory modes can be delayed until later, and with films living entirely in digital form (Manovich, 2013), layers can be continually reworked upto and beyond the production of a finished film.

Now that I have covered theories related to the media studies component of 3D animation, I turn my focus onto *computational thinking*, a theory related to the computing element of 3D animation creation.

3.4 Computational Thinking

This section outlines the computing concept of computational thinking, looking at the current debates into its definition. In particular, it outlines the argument for the inclusion of automation in any definition. Finally it makes links between computational thinking and digital art.

3.4.1 What is computational thinking

Computational thinking (CT) is a method of problem solving that allows us to reformulate "a seemingly difficult problem into one we know how to solve" (Wing, 2006, p. 33). It is essential for the development of computer programs but it can also be applied to other domains including the humanities (e.g. Bundy, 2007; Barr & Stephenson, 2011). This section will look at the link between 3D digital art and computational thinking. Wing (2011) defines computational thinking as "the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent", where the information-processing agent might be a machine or a person.

Computational thinking is increasingly being referenced within computing curricula (Wing, 2011) and now forms a key part of the new English computing national curriculum (DfE, 2013). However, there remains significant debate around the definition of computational thinking (e.g. Tedre & Denning, 2016; Kong, Abelson, & Lai, 2019). Wing (2011) lists a range of features of computational thinking, including: *use of randomisation, reduction, embedding, transformation, simulation, recursion, parallel processing, generalization,* *correctness, efficiency, aesthetics of code, abstraction, decomposition, modularising, prevention, protection and recovery from worst case scenarios*. In contrast, Google (2015) mentions: *abstraction, algorithm design, decomposition, pattern recognition, automation, data analysis, data collection, data representation, pattern generalization, parallelization and simulation*. Many other definitions exist. Selby and Woollard's (2013) literature review attempts to find a consensus in the definition of computational thinking, settling on it being a thought process that reflects: the ability to think in abstractions; the ability to think in terms of decomposition; the ability to think algorithmically; the ability to think in terms of evaluations; the ability to think in generalizations.

Using these concepts I now outline their meanings and then show how 3D animation relates to them.

Decomposition involves the breaking down of large problems into smaller ones to which solutions can be addressed (Barr & Stephenson, 2011). This is required when dealing with complex problems, encouraging the creation of modular solutions that allow for the "separation of concerns", where modules might be developed in isolation from each other, possibly by different people. For example, a car racing game might require the creation of programmed modules including a physics model, sounds, graphics, a user interface system, artificial intelligence for computer controlled cars and a network system to play the game online. Each of these modules might be developed by different programmers and then brought together to create the overall game. At the same time, each module might be further decomposed. For example the sound module might include background sounds, music and engine noise. Decomposition in digital art is more forgiving than in programming "If a particular module of a computer program is deleted, the program would not run. In contrast, just as it is the case with traditional media, deleting parts of a new media object does not render its meaningless" (Manovich et al., 2001, p. 52)

Wing (2011) defines **abstraction** as being computational thinking's "most important and high-level thought process", where the user attempts to "capture essential properties common to a set of objects while hiding irrelevant distinctions among them"; For example, when creating a computer game a car might be modelled as having different numbers of seats, being petrol, diesel or electric, or having the capability of using four-wheel drive. The presence of a sunroof or CD-changer in the boot would be irrelevant details for such a game and omitted from the model used in the game's development.

Colburn and Shute (2007) recognise another element to computational abstraction: *information hiding*, where interactions with modern computer systems, involve interactions with abstractions of what is happening at the software and hardware level. For example, when you click the print button on a computer, the button masks a host of program code and the functioning of the hardware that executes this code. This form of abstraction, also known as procedural abstraction, doesn't jettison any detail, it's still there, just hidden from the user. "The ontology changes because the underlying technology increases speeds and decreases sizes so much that new generations of machine allow old structures to be subsumed by higher abstractions." (ibid. p175). They also touch on Wing's (e.g. 2008) version of computational abstraction, terming this *information neglect*. Both versions are studied below.

The development of abstractions requires recognising patterns, creating **generalised** models from these patterns and creating a representation in a parameterised form, where this model can be used to model a range of instances. For example, our car example might lead to the following parameterised model:

Table 3.2: car example of generalisation

Generalised Model	Instance 1	Instance 2
Car Model	"Off-Road"	"Sports Car"
Parameters		
Number of Seats	5	2
Fuel	Diesel	Petrol
4WD	Yes	No

The abstract model that has been built on a generalisation, such as the one described above, can then be combined with other abstractions to solve new and different problems (NRC, 2010). Using our computer game example, the car model could be reused when making a racing game, or when making a city simulation. More specifically to programming if we to write a program to create a triangle, and were then to write a program to create a square, we might notice a similarity in the pattern of code produced and create a generalised program that could output a shape when given the number of sides (Curzon, Dorling, Ng, Selby, & Woollard, 2014).

An **algorithm** is an interdisciplinary term defining a step-by-step procedure for accomplishing tasks. Algorithms are the end result of the computational thinking process, they are the representation of the solution that Wing (2011) describes as being "effectively carried out by an information-processing agent" (Selby & Woollard, 2013). Specifically within computer science, these can be linked to the process of computer programming. However, other examples might include the creation of a recipe or the instructions on how to get from one location to another. In the computer game example above, algorithms would be used to develop the functionality of each of the decomposed modules. To think algorithmically is to develop algorithms;

one proposed method to develop algorithms is Futschek's (2006): the ability to analyze given problems; the ability to specify a problem precisely; the ability to find the basic actions that are adequate to the given problem; the ability to construct a correct algorithm to a given problem using the basic actions; the ability to think about all possible special and normal cases of a problem; the ability to improve the efficiency of an algorithm.

There may be many solutions to the same problem when thinking computationally. **Evaluation** incorporates the efficiency of a solution, how computational time and computational space were used, with the solution potentially having to make trade-offs. One solution might run faster on the same hardware than another; another solution might use less computer memory (Wing, 2006). Evaluation also includes the comparison of a solution against the original goals (L'Heureux, Boisvert, Cohen, & Sanghera, 2012).

3.4.2 Making and computational thinking

Wing (2008) argues that computational thinking can be enhanced through the use of automation: "The power of our 'mental' tools is amplified by the power of our 'metal' tools. Computing is the automation of our abstractions" (p.8). Automation might be the process of creating a digital artefact, for example a program to run on a computer. Popular definitions of computational thinking include "algorithmic automation"; this implies that an automation should be based on an algorithm, though it should also be noted that other definitions of computational thinking are possible (ISTE & CSTA, 2011). Barr & Stephenson (2011) argue for a cross curricula interpretation of computational thinking, providing examples of automation that are not examples of algorithmic thinking, e.g. using a spell checker. It is therefore reasonable to conclude that automation does not have to be based on an algorithm created by the computational thinker, but it might use an algorithm already existing within a computing device.

Selby and Woollard (2013) don't see consensus in the literature on automation being a core component of computational thinking, stating that the artefact created by automation "is only evidence that computational thinking has taken place". However, without an automation to evidence that computational thinking has taken place how else can we be sure that it has taken place? Evaluating the efficiency and suitability of a solution becomes nothing more than a theoretical procedure.

Furthermore, Brennan & Resnick (2012) argue that people engaging in the development of external artefacts, e.g. the creation of automations based on their computational thinking, provides a suitable method for helping students learn about computational thinking. This model of learning is called constructionism and it suggests that one of the best ways to learn is through making public artefacts that can be shared with others (Kretchmar, 2015; Papert & Harel, 1991). If children are to learn computational thinking, they must be actively involved in the creation of artefacts/automations.

The task now shifts to looking at what sorts of automations/artefacts can be produced to learn computational thinking. Hu (2011) notes that teachers are confident that the teaching of computer science does promote computational thinking. Brennan & Resnick (2012) argue that students can learn computational thinking through programming interactive media; if we accept that programming is a key part of computer science (Kemp, 2014b), then this supports Hu's observation. But as noted earlier, computational thinking can be applied across disciplines (Bundy, 2007), so how effectively can computational thinking be incorporated or learnt in other subjects? Brennan and Resnick (2012) ask: "What is the learning that is supported by programming interactive media, as opposed to making a video with editing software or playing a video game?" (p.2). Flipping this question, I ask: "How is learning computational thinking different in making 3D digital films, as opposed to programming interactive media"

Many people have already explored the link between digital art and computational thinking (e.g. Resnick et al., 2009; Orr, 2009; Rim & Lee, 2012), however, the work is mostly in the form of expressing programming through digital art, using the Scratch and Alice programming environments and the processing language. Perković et al. (2010) made an attempt to fit animation and 3D modelling into a computational thinking curriculum, though the exposition of these topics is limited i.e.: "Techniques such as abstraction, modularization, automation, and randomization are necessary to create realistic models that can be efficiently designed and processed" (ibid. p.127). I have attempted a similar exploratory paper which was largely theoretical (Kemp, 2014a). A large gap still exists in the literature to link computational thinking with 3D animation, but before I move on to this I must first address the importance of software choice in influencing the development of digital art.

3.5 Software

> [O]ne consequence of the digital era has been to confer the tools of media production on the population at large, and the artist formerly known as 'audience' has become maker, producer, and creator (Burn, 2016, p. 6)

Blender is an industry standard open source 3D creation tool that allows the user to create a range of outputs including 3D models, films and animations (Blender Foundation, 2019). There are many other tools that could have been chosen to run the summer course behind this thesis. This section will outline the argument that converting the audience into the makers, producers and creators of 3D animation is best suited through using an industry standard tool such as Blender, rather than commercial or pared down alternatives.

It might have been strange thirty years ago to include a chapter on the choice of software for creating films with school children. The tools to make videos were generally physical tools such as film cameras and audio tape; where computer hardware and software were used in industry, they would have been prohibitively expensive for a school or school children to afford. Nowadays media *is* data, and rather than having multimedia in the form of filmstrips, paint, chalk etc, we now have one platform that can perform all media manipulation, the binary computer (Manovich, 2013). A computer is not just a film editor, a compositor[12], or a modeling tool, it can act as all of these tools and more: "It is the first metamedium, and as such it has degrees of freedom for representation and expression never before encountered" (Crookall, 1988, p. 1). With the increasing importance of software in media creation (Manovich, 2013) and its ability to democratise the development of media (Buckingham, 2003), the choice of software will have a huge influence over the way students create media and what they create (Sefton-Green, 2005).

Nelson's (1965) prediction of *hyperfilm*, a non-linear format where people choose the order and content of the film they consume, hasn't come to pass in the way many might have envisaged it. We still largely consume films in a linear way albeit through different devices and in different settings. However, the last few decades have seen huge changes in the way that films are made. No longer are we stitching physical frames of cellulose triacetate together, everything now revolves around the storage, retrieval and manipulation of images and sound stored as binary digits. The editing opportunities afforded by digital file systems have taken over the world of film production. When looking at computer media editing, the definition of a medium has become algorithms interacting with a data structure (Manovich, 2013).

Whilst it should be noted that learners might not be interested in the way the data that comprises the components of a film is stored, they are interested in "manipulating the representation of affect" (Burn, 2016, p. 324). This is where the limitations and affordances of software become important. The choice of software will limit the representations available to a student, both in terms of what data they can ingest into their editing and the outputs that are available.

Previously, film making would involve the shooting of actors on a pre-made set, then linking this to a sound track and cutting the film to fit a director's tastes. Elements of this work would have seemed to be indivisible, for example if a car drove through the background of the shot whilst filming, the filming would have to stop and the shot would have to be retaken. Modern filmmaking breaks apart these indivisible elements into layers, that we can stick together, break apart, change and stick together once more (Manovich, 2013). The layered approach means that the car driving through a shot could be layered over through compositing, with a mask covering the offending vehicle. The background might also be another layer, made entirely inside

[12]a compositor is a tool used for post-production adding of special effects, color correction etc.

a computer and placed behind the actors through the use of 'greenscreen' technology. Things that might previously have been impossible are now possible through software (Manovich, 2013, p. 176), for example bringing to life dead actors by projecting 3D scans of their faces onto living actors. We are no longer held to blocks of time being the smallest element we have to deal with, we are able to reach into individual frames and manipulate items within, "each visual element can be independently modulated in a variety of ways, resized, recoloured, animated etc." (Manovich, 2013, p. 281). Burn (2016) calls such activity *lamination*, where "the semiotic process is one of building up, accretion, thickening of signifier material" (p.4). Additionally the digital basis and modular nature of a media object allows for the automation of "many operations involved in media creation, manipulation and access" (Manovich et al., 2001, p. 53). The computer both augments and automates the processes of the traditional media creator.

Reid et al. (2003; cited in Burn, 2007, p. 511) describe three features of digital media creation, and thus media software: "feedback, dynamic representation and iterative opportunities for editing". With *feedback* meaning instant viewing of a work in progress, for example through edits happening on and being displayed by a computer screen; *dynamic representation* meaning finished works can be displayed in multiple ways, for example on TV, cinema and the internet; and *iterative opportunities* for editing meaning that students can go back and edit elements of their film, in line with Andrews & Hawthornethwaite's "the endless rework of the finished piece" (2007, p. 511). The availability and choice of software will allow for the 'lamination' of different software signifiers (Burn, 2013) and differing levels of Reid and colleague's feedback, dynamic representation and iteration. It is to this availability and choice of software that I now turn by looking at the the choice of open source software programs.

3.5.1 Freedom

Open source software is software that has a license of use meeting specific criteria. These criteria include the right to freely distribute the software and to look at and change the code behind the software (Perens & others, 1999). The right to free distribution means that open source software, such as Blender, is usually available for free to schools and other users. There are several arguments behind using open source software in school, including cost savings, the use of the products by students at home and the ability to run open source software on older hardware than required by equivalent commercial products (Becta, 2005), as well as the availability of ongoing free upgrades for the products and the ability to import free plugins and tools (Lakhan & Jhunjhunwala, 2008). Cost is a real concern amongst educational institutions, with school funding cuts (BESA, 2019) leaving less money for investment in resources including hardware and software: in 2018 35% of computers in secondary schools were judged as "ineffective" (George, 2019). Amongst colleges offering

3D animation courses in the US, a third of them had software and hardware as the main major financial burdens on institutions offering VFX/graphics courses (Aoki & Koning, 2011).

There are, however, some potential drawbacks with open source software use: incompatibility with other software and lack of trained staff to teach it accompanied by extra staff training costs (Becta, 2005). Lakhan & Jhunjhunwala (2008) also mention that the ability to look at the source code is far less important than the availability of support for most educational users. With the fear that many open source projects, often being run by volunteers, will lack the financial structure to provide the support needed by end users.

A quick search (Table 3.3) for tutorials for different animation/3D modelling packages shows that the 2D animation platform Scratch has the most resources. Amongst the 3D packages Blender comes out top, beating equivalent commercial packages. This isn't a judgement on the quality of the tutorials and their suitability for schools, but it is an indication that support materials are being created and are available to support schools. Additionally, the Blender Foundation that develops Blender has multiple funding streams for ongoing development (Vazquez, 2019).

Table 3.3: Google search for different tutorial sets, 31st January 2019

Results	Description	Product	Search term
19,100,000	3D modelling tool	SketchUp	SketchUp tutorial
272,000,000	Open source programming platform used to make 2D games and animations	Scratch	Scratch tutorial
4,060,000	Commercial 2D animation product	Adobe Animate	Adobe Animate tutorial
31,500,000	Open source 3D animation tool	Blender	Blender 3D tutorial
27,800,000	Commercial 3D animation tool	Maya	Maya 3D tutorial
19,800,000	Commercial 3D animation tool	3DS Max	3DS Max tutorial
22,000,000	Commercial 3D animation tool	cinema 4d	Cinema 4d tutorial

Whilst it might make sense for a school to choose an open source software package for the freedom of usage that it offers a student, one must also consider the artistic possibilities possible within a tool. I now look at software choice in terms of software affordances.

3.5.2 Affordance

I now look at software in terms of the *affordance* it provides for 3D animation. Gibson (2014) describes affordance as "what an environment offers the animal, what it provides or furnishes, either for good or ill" [p.127]. For Gibson this means all possibilities of the environment, even if the person is unaware of them (Soegaard, 2015). Norman (1988) gives a slightly different definition, linking affordance to perception of the environment it inhabits "…the term affordance refers to the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used", e.g. if you didn't realise that you could use plugins with your software to add green screen capabilities, your affordance of this software would never include this. Norman's affordance is wedded to the culture of the person in the environment (McGrenere & Ho, 2000) and in that sense it is important for us here, as education and learner environment can directly change the perception of what something can and cannot do.

For the purpose of this work I look at the affordance offered to a student by the environment of the software they use in relationship to their education, evaluating this in terms of 3D digital animation outcomes. I split affordance both into *internal* expression and *external* expression. *Internal expression* incorporates the range of tools available for a student to express themselves within a software product and the outcomes available within the tool, e.g. on the screen they are editing with. *External expression* describes the range of platforms and formats available for a user to share their work, similar to Reid and colleagues (2003; cited in Burn, 2007, p. 511) "representation". For example, the Scratch[13] programming language does not allow for the use of object orientated programming and 3D models, these are limits on the *internal expression* of the tool. For external expression, Scratch projects are open source by default,[14] meaning that anything you make can be freely remixed by someone else. But they are limited in terms of platform, where they can only be displayed in a web browser or the bespoke Scratch App, conversion to film format or to make a Scratch game run on a given computer games console is not possible as such capabilities are not native to the programming platform itself. A Gibsonian (2014) interpretation of the affordance might allow an agreement between the student user and the Scratch developers to change the licensing and stop other people remixing their work. Other tools or programming could be used to create a video from the Scratch tool, or convert a Scratch game to run on a computer games console. The complexity of these tasks would be beyond the average school student, or the tools needed to perform these tasks unavailable unless a teacher enabled them. Norman's (1988) affordance is a more useful concept to frame internal and external expression as it incorporates the limitations imposed by the learner's environment, e.g. they would be unlikely to come to an agreement with the scratch developers to change the licence.

[13]Scratch is an online block based programming language developed by MIT
[14]https://en.scratch-wiki.info/wiki/What_license_are_Scratch_projects_under%3F

Some commercial 3D tools cost money for educational use, meaning schools with limited budgets will struggle to afford the products and students from poorer backgrounds will be less likely to afford to run these products at home. Other tools come with free educational licensing, but the products often have heavy technical specifications, meaning students will struggle to use them on their computers at home or at school. Other software products are only available on one operating system, meaning that schools might not be able to run them, and students might not be able to run them at home (Kemp, 2016 gives an overview of competing 3D creation packages). Hardware limitations of a software product will influence *internal expression*, by limiting the range of tools and complexity of work that is feasible on a piece of hardware and operating system. This links directly to the idea of "feedback" proposed by Reid and colleagues (2003) where attempts to edit work or represent work in progress on the screen might be limited by resolution or refresh rate due to underpowered machines. Additionally, if you don't have a fast processor it will make modelling complex characters made up of hundreds of thousands of polygons almost impossible. Hardware limitations might also affect the range of external expression (or "digital representation" outlined by Reid and colleagues (2003)), as output video might be limited to a certain resolution, or students might not be able to run the software at all on the system they have at home. Limitations on where a software product can be used and the ways in which it can be used may have an impact on a student's ability to acquire knowledge of the *domain*, restrictions on the outputs available from a tool may place limitations on a users interaction with the *field* (Csikszentmihalyi, 2013), a lack of access to the right tools at home or at school is a sign of lack of computing *capital* (Archer et al., 2015).

Where student educational licenses exist, it is often the case that students will not be allowed to create commercial work under those licences, and in some cases there is a watermark placed on any work created to make it known that the tool used was under a free educational licence.[15] This influences the *external expression*/representation in terms of students trying to make money from their work, or forcing all work to be branded with a company logo, limiting the *internal expression*.

There are tools available for 3D digital art that have learner focused interfaces, for example *Alice* by Carnegie Mellon University[16] and *SketchUp*[17]. These tools are used extensively in education (e.g. Cooper et al., 2000; Dann et al., 2008; Hart, Early, & Brylow, 2008), but the *internal expression* of such tools is limited when compared to professional tools, e.g. whilst Alice might be good at creating simple 3D animations, it lacks the ability to composit the results or use procedural textures. Sefton-Green (2013, pp. 39–40) describe the

[15]e.g. AutoDesk Forum "You cannot use any portion of work created in the educational version for commercial purposes. It is a violation of the license agreement. It is also a violation to make any attempt the circumvent the educational stamp." https://forums.autodesk.com/t5/installation-licensing/can-a-commercial-game-be-worked-on-under-student-license-maya/td-p/7094261
[16]https://www.alice.org/
[17]https://www.sketchup.com/

debate around the tools used for programming in schools, comparing learning languages, such as Scratch and Lego Mindstorms, to more commercial tools : "[what] is the value and purpose of teaching (and learning with) such languages as opposed to moving more directly to the 'hard' core programming languages in use by the industry?". This is an important question for those wanting to teach or learn 3D digital animation, how does age and experience impact the user's ability to grasp an industry standard tool when first learning it, what are the issues around using 'cut down' software, or learning the industry standard from the offset?

Our interaction with software isn't an interaction with a static object, but an interaction with potentials. However, at the same time, affordances provide both opportunity and constraint (Hammond, 2010), for example the affordance of a 3D animation package might be that it allows you to create a physics simulation, but those physics simulations require a very fast computer processor, so you have to limit the complexity of your simulation and what you might attempt to represent. The way we perceive opportunities and constraints is based on the interactions of own predispositions and the construction of the software we are using. Often a software package "enforces compromise or, worse, inhibits creativity through unwelcome constraints" (Hugill & Yang, 2013, p. 5), but additionally the constraints might be useful in terms of setting up a suitable learning environment.This balance between opportunity and constraint is covered below.

3.5.3 Opportunities and constraints

> As is true of the play itself, the children should be invited to create all the materials needed for the play. Just as burdening children with someone else's lines leads to a disruption in the children's psychological set, so the objective and basic nature of the play should be compatible and understandable to the children. (Vygotsky, 2004, p. 73)

A simple way for children to make 3D digital films is through machinima. Machinima allows the user to manipulate premade 3D graphics to act out stories, for example by recording their own actions in a computer game. Burn's (2009) work with machinima and school children notes the potential of such a platform, stating that it "makes possible [...] shots which would normally be quite beyond the technical possibilities of school productions" (p.149). For example, a computer game might allow students to make a film set in a weightless environment, a scenario beyond the capabilities of the school drama studio. But Burn (2009, p. 139) also notes the constraints of machinima, "[t]he communicative repertoires [in Second Life, an online world simulator] of gesture, facial expression, intonation are much more limited than in RL [Real Life]".

There are obvious constraints in expression placed upon the user by the software itself. These limitations might be termed "physical attributes" of the system, e.g. you are always limited to having one mouth on a character, the hair can only assume 10 different styles. Whilst the limitations are clear, they might not always be bad. Constraints within a system can support as well as hinder: "pre-programmed samples of music encouraged the composition process by acting as stimulus and a facilitation for composition but were a constraint on creativity by limiting the range of composition, particularly for more able students" (Hammond, 2010, p. 8). When dealing with learners we must take into consideration the optimal *learning* environment. This environment can be described as one where the learner is engaged with a meaningful and authentic activity, where their abilities are balanced against the challenge of the activity, and they have the tools to express their emerging knowledge (Csikszentmihalyi, 2013). Kennewell (2001) sees constraints in the environment as being important for supporting a learner, as such restrictions will reduce the cognitive complexity of the work undertaken. Additionally, Sadler, Shluzas, & Blikstein (2017) found that the "likelihood of creating novel [electronic] prototypes" (p.1) corresponded with simpler interfaces as it reduced errors amongst beginner users. The issue here is providing a tool that can offer the correct amount of challenge, whilst being able to increase the challenge in line with the learner's capabilities.

There is the fear that by using industry standard tools we will limit young digital makers rather than inspire them. Buckingham (2003) suggests that a project should "keep activities small-scale and manageable. Students will avoid disappointment if they understand the limitations of the available technology and adjust their ambitions accordingly." (p.84). But do we need to limit their ambitions? By a student using the same tools used to make the media they consume, they may well be more engaged in their learning and set their ambitions higher, to recreate what they have seen elsewhere. Garneli et al. (2015) argue that the authenticity of the tool and the learning experience might inspire some students. This suggests that students should try and use industry standard tools, as they are authentic in that they are also used to make the media that the students consume. There is an issue here around the suitability of child focused and limited tools to maintain an optimal learning environment. A student might eventually hit the limitations of *internal expression* of their tool e.g. they want to create a dog in a program that only offers humanoid characters, either they limit their ambitions, compromise the output (e.g. by pretending that an excessively hairy man is a dog), or have to shift to and learn an entirely new tool. Taking into account that the perception of the affordance of a technology is linked to past use of similar technologies (Armstrong et al., 2005) and that "affordances are often sequential and nested in time" (Hammond, 2010, p. 12), the ability to use one tool and interface that offers learning complexity that can be repeatedly increased, to the highest level, fully interacting with a student's abilities and interests seems important. Professional tools used have fewer limitations; indeed they provide freedom well beyond the physical restraints of traditional media making setups and that of simplified systems such as machinima.

The user interface shapes how the user thinks about media manipulation, "In semiotic terms, the computer interface acts a code that carries cultural messages in a variety of media" (Manovich et al., 2001, p. 64). For example, having the options to change the height of a character through a slider is an invisible line of force, to encourage you to think about the use of height in your production, where without that slider you might not have considered it and focused on the width or colours instead. In Burn and Kress's (2018) project with students making werewolf movies, decisions about meaning were influenced by the software tool: "the complex of signifiers used by the students to represent the werewolf were partly drawn from the cultural experience of the children, *partly from the material assets provided by the technology*, and partly from the physical resources of their own bodies" (p. 7, emphasis mine). Burn & Kress (2018) compare their students' work and work produced in industry, noting that "the basic principles are very similar" (p.15). Whilst this is true in terms of a standard set of film semiotics, the limitations that the tool placed on student expression remain underexplored. For example, all students appear to have had only one base grey haired werewolf model to build from; what difference would it have made if they had had more variety here, a blonde or black haired werewolf, or the ability to build their own model? How would this have changed the *internal expression* available to the learner? Whilst there has been much theoretical work on the impact of interfaces on media output, it should be noted that there has been very little empirical work (Gilje, 2011).

Burn (2014) argues that we need to "focus on authentic digital craft tools of the digital arts, rather than on educational technologies and 'edutainment' softwares" [p.19]. Looking at the number of outputs from machinima or Scratch creators it is clear that these tools have a level of authenticity that might resonate with students, i.e. they will be able to create forms of media that they themselves consume. Sefton-Green (2013) poses the question that assuming the focus of learning programming in school is to get the students closer to the code, does the use of *Scratch* etc "represent another level of obfuscation between the maker and the code"? [p.40] What is the equivalent for 3D digital animation? Does the use of a tool like SketchUp, or Machinima introduce a layer of obfuscation between a student and their ability to express themselves more fully through 3D digital art?

Arguments might be made here about learning transferable filmmaking skills in a more limited tool that can be taken into more complex tools when ready. Similar arguments have been made in programming education. Studies into the transferability of computer programming skills show that (Guzdial, 2018) "Student knowledge of programming is tightly tied to the syntax of their first language", and that "[a] move between languages too soon [...] may actually *delay* their development of the deeper levels of understanding". Whilst lacking research specifically into the use of 3D animation tools, the parallels that can be drawn are that student understanding of film semiotics is rooted in the interface of the tool that they use. Shifting between tools might delay the development of an understanding of film literacy and delay the development of software skills that might be used across other domains. This suggests that any software tool that students use should be flexible enough to allow them to master the skills in it and we should avoid switching between tools where possible.

Films often involve several stages of development, I now focus on the pipeline used in film creation and the layering of film assets and semiotic signifiers.

3.5.4 Pipes and layers

A pipeline is the flow of data between the stages of film production, for example the film of an actor in front of a green screen might be sent to a 3D modeler to combine with a set of a space station, this set of images will then be sent to a compositor who will adjust the lighting and add motion blur. Often this will mean the use of different software by different parts of a studio with people dedicated to making sure that data leaves one program in a format that another program can handle (Whitehurst, 2018). Whilst 2D image manipulation has seen a flattening of the number of tools needed in its workflow (Manovich, 2013, p. 324), in 3D digital animation there are normally multiple tools needed to complete a film. For a learner trying to create a film they will have to create their own pipeline, this might involve moving between different functions inside a program or between different programs and file formats with the accompanying cognitive overhead of having to learn multiple interfaces. For example, they might make the sound in *Audacity*, the title screen in *Photoshop* and the raw film footage using their phones, then import the image, video and sounds into *Final Cut Pro*[18].

One of the three affordances of new media outlined by Reid and colleagues (2003; cited in Burn, 2007, p. 511) is the "iterative opportunities for editing", which matches Buckingham, Grahame, & Sefton-Green (1995) "Practical work should be recursive: the product should not be seen as the end of the process … a starting point for reflection or redrafting, and the basis for future work" (p.226). This idea can also be described as "Deep remixability […] allows designers to remix not only the content of different media types, but also their fundamental techniques, working methods, and ways of representation and expression" (Manovich, 2013, p. 46). In Burn's (2016) terminology we need to "[dig] through the laminates to the layers that need adjusting" (p.32). Different layers might include sound, images, characters, sets, animations and so on. However, the ability to iteratively edit a media product means that the components of that product need to be in an editable format. Whilst most media editing software will offer some means of editing the product iteratively, some modes of media creation will place limitations on this. For example, a live action film being cut together on a computer will probably need shots to be redone if they are not up to scratch, as the contents

[18]Final Cut Pro is a film editing suite

of the video itself is not editable within a standard video editor. The film strips are pre-*laminated* and cannot have their layers of actor, set, lighting etc separated. Moving more of the representation into an expression controlled by a computer will offer increased ability to edit the layers of media representation. For example, Burn's (2016) work with machinima moves the characters and sets into different layers that are edited separately then brought back together. There are also constraints within this method, as noted above, you might not be able to remix the main character to be a talking dustbin, or the stages are selected from a set number of options. To remix these elements would involve scrapping the rest of the work and starting afresh, maybe requiring a different software program. When considering 3D software products the "deep remixability" available needs to be considered and weighed against the ease of use of the tools.

Many media tools have now adopted programming interfaces as well as menu systems; these interfaces allow the user to construct their own tools within a software product. Programming interfaces take two forms, (normally) procedural programming and node based programming. Node based editors are a common way of programming media, allowing for multiple objects to interact with each other at the same time through a drag and drop interface of blocks that link together (Manovich, 2013, p. 310). Procedural programming languages can expand the nature of the media editing suite allowing for users to extend functionality, automate tasks and build tools for other people to use. The scope of such programming interfaces influence our interpretation of *internal* and *external* expression, as both modes might be able to be expanded as much as you wish to make the software tool do anything. If a programming language is "Turing Complete"[19] then the program, and thus the media software it is embedded in, will be able to perform any task that is computable, thus giving the software the capability to perform any calculation achievable through any other software (Czerkawski & Lyman, 2015; Turing, 1937). Some node based editors lack the ability to form recursion and loops, this means that whilst they can be used to automate some processes their capabilities are more limited than a "Turing Complete" language. This might appear to make claims about internal and external expression redundant for any tool with a "Turing Complete" programming interface, as you could emulate any functionality, remove watermarks etc. But as argued above, Norman's (1988) definition of affordance is more useful here and with it we can see that whilst programming is important for expanding the possibilities that a tool brings, the ease at which all these possibilities can be fulfilled, especially by school children, also needs to be taken into consideration. Examples of "Turing Complete" media software include the game "Minecraft" (Timko, Nick, 2011), albeit the system created is unusably cumbersome if you were trying to emulate even a basic image editor.

[19]"A computer or a programming language is said to be Turing complete if it can implement a Turing machine. A Turing machine is a mathematical model of computation that can, in principle, perform any calculation that any other programmable computer can." https://chortle.ccsu.edu/StructuredC/Chap01/struct01_5.html

There are clear differences between the available outcomes of different media manipulation software. Microsoft Movie Maker allows you to use 78[20] different transitions between shots, Final Cut Pro gives you even greater flexibility in what you produce, whilst something like Blender would allow you to use default transitions and program your own if you can't find the right one. "Turing complete" is a great way to describe a system than can perform any task that is computable, but we are lacking grammar here for gradations of "*expression* complete", the degree to which a media tool allows the creation of any art work in a digital form.

I have outlined how software is used and how it can influence film development, I now provide rationale for the choice of software used in 3Dcamp: Blender.

3.5.5 The argument for Blender

Kay (1990, p. 125) argues that "[t]he ability to read in a medium means you can access materials and tools generated by others. The ability to write in a medium means you can generate materials and tools for others. You must have both to be literate". Only being exposed to a limited set of materials and tools, and limited in the outcomes that you can make will leave you less literate than someone who has access to the whole set. However, it isn't as easy as just picking the most complex tool you can find, as the constraints of a tool are cultural as well as hardcoded. Does the tool allow for easy use and support? Here I outline the reasoning behind choosing Blender as a media creation tool for a 3D animation summer school. A summary comparison of different 3D animation tools is given in figure 3.1 below.

[20] https://www.minitool.com/moviemaker/add-transition-to-video.html

Name	Free	Multiplatform	USB	Minimum spec	Commercial projects	Full pipeline	Students prefer it
Blender	GPL license	Mac, Windows, Linux	Yes 600MB	32 bit CPU, 2GB of RAM, Graphics card with 512MB	Yes	Yes	?
Maya	Student licence 3 years	Mac, Windows, Linux	4GB install	64 bit CPU, 4GB of RAM, Highly recommends a dedicated graphics card	No	No	?
3DS Max	Student licence	Windows	6GB install	64 bit CPU, 4GB of RAM, Highly recommends a dedicated graphics card	No	No	?
Modo	Student licence	Mac, Windows, Linux	4GB install	64 bit CPU, 8GB of RAM, Graphics card with 512MB	No	No	?

Figure 3.1: comparison between industry standard 3D creation tools (Kemp, 2016)

Any tool selected should be *democratic*, this means as far as possible the restrictions on internal and external expression should not be limited. An open source tool such as Blender is free to use, with it costing no money to download and install, it is also free in terms of expression as the license places no restrictions on its commercial use. Nor does the software limit the attributes of the outputs by requiring watermarks etc. The hardware recommendations are less than those of similar products meaning it will work on older, less expensive hardware such as that found in schools. Blender also runs on the major operating systems, in line with most of its competitors[21]

Fears about lack of support appear to be unfounded as there are more tutorials available for the Blender than for its competitors (See Table 3.3). However, the overall need for particular teacher training to help this run in schools remains unknown and the quality of these tutorials has not been established.

The affordance of the software allows for the creation of almost any visual outcome you can imagine. You are not limited to set models with the ability to free form edit, texture and animate. The range of outcomes include 3D models, 3D printing, VR, AR and animations. In terms of "expression complete", Blender is closer to being a universal media creation tool than tools like Scratch, SketchUp or programs used to make machinima. Blender can be used for most of the pipeline needed for media creation, meaning only one

[21] Whilst not natively supported, it appears possible to install Blender on Google Chrome OS through a 'Linux container' https://www.androidpolice.com/2018/08/19/install-linux-applications-chrome-os/

interface needs to be learnt to perform multiple tasks.

The perception of affordance is questionable, as many of the features that can be used with the software might not be immediately accessible to a user. An incremental pedagogy is needed here. If these tools are learnt in a structured way students can then progress from the basics to advanced skills without having to undergo the discomfort and confusion of switching to a new tool with a new user interface. Creating visual effects and animations using the tools that are used in the cinema is not beyond the scope of most secondary school children and limiting their outcomes by using limited software may cut down their ambitions unnecessarily. Examples of children aged 6+ using Blender are hosted on the b3d101[22] project website.

Blender has both a node editor programming language and integration with the "Turing Complete" python programming language. This means that the functionality of the software can be extended if necessary by the user, and at the same time programming skills that students might already possess can be used inside Blender.

The object of the exercise above was to reason out the best software solution for a 3D animation summer school, the project behind this research. Other pieces of software might be more suitable for other purposes in different environments with different constraints. We must attempt to balance the difficulty of using a product against the affordances it offers for student expression. Burn (2016) states that the "appeal of [machinima] animation is its readiness to represent the 'impossible image' " (p.324). Many impossibilities can be dismissed in the creation of machinima, but it is the broader range of impossibilities that we must wrestle with. What 'impossibilities' the choice of media tool imposes on a user depends on multiple factors including economic, developmental and social circumstances, and all should be considered when we choose software.

3.6 Summary

This chapter argues for the importance of 3D animation and looks at the theory behind its subject domain. I split the subject domain into multimodality (Kress & Van Leeuwen, 2001), computational thinking (e.g. Wing, 2006), looking at both of these theories separately, finally I outline how software choice can influence artistic outcomes (e.g. Manovich et al., 2001)

Part of the importance of learning 3D animation is that it provides *powerful knowledge* (Young, 2007) to students, allowing them to understand how the media they consume is made, as well as allowing them to engage with critical discourse around the media messages that they are subjected to daily. Another reason

[22]htttp://b3d101.org

to study 3D animation is the economic needs of the country (e.g. Djumalieva & Sleeman, 2018) and the potential jobs that this can lead to.

Media literacy is outlined (e.g. Buckingham, 2003), with a focus on multimodality (Kress & Van Leeuwen, 2001). I argue that there is a lack of literature on the interaction between software, hardware and teams in influencing student media production. With a focus on Burn's (2013) *kineikonic chronotope* I argue that the order of development for contributory and orchestrating modes for the described machinima project can be more fluid than presented; with software, in particular 3D animation software, allowing for the development and remixing of signifying modes at almost any stage of development.

I argue for the importance of *automation* in digital making, a computational thinking concept not accepted by everyone (Selby & Woollard, 2013). Looking at the use of computational thinking development of programmed interactive media (e.g. Brennan & Resnick, 2012), I pose the question whether computational thinking can be learnt so well outside programming, i.e. in 3D animation and the creation of automations that require no coding. I note that work on linking 3D animation to computational thinking has largely been theoretical (Kemp, 2014a).

Software can be considered in terms of the affordances it offers the user. I argue for Norman (1988) interpretation of affordance, where possibilities with a tool depend not just on what is theoretically possible, but what the situation at any moment allows, with the influence of social setting. I develop the concepts of *internal* and *external* expression as a way of understanding how software represents things inside a computer and as a finished product, and as a means by which we can judge the suitability of software choice for young digital makers. Building on the concept of a computer being Turing complete (Czerkawski & Lyman, 2015), I theorise that we can evaluate whether digital art software is *expression complete*, where it can represent any possible artistic output.

Finally I argue that Blender, offering the greatest affordances for digital creation in terms of internal and external expression and being an authentic (e.g. Burn, 2014) tool that links to how media is made in industry is the best tool for teaching 3D animation.

4 Curriculum: content, pedagogy and assessment

Robinson (2011) argues that “Creativity and innovation work best where there is a balance between the freedom to experiment and agreed systems of evaluation” (p.221). Creating an educational environment suitable for creativity tasks, one with the creation of a suitable curriculum and assessment model, as well as a pedagogy that will allow students to be creative. This chapter looks at how a creative curriculum for a summer school could be made and potentially assessed and how the 3Dcamp summer school maps to current research and thinking behind creative education. I choose here to study curriculum as being the interaction of content - the domain of a subject, pedagogy - the way that the subject is taught, and assessment - the way that a subject is validated. I cover each of these topics separately.

First, I link the content of the course to Csikszentmihalyi’s (2013) concept of *domain*, with creativity being supported by the acquisition of a domain of knowledge. In particular, I look at content for a creative curriculum involving a range of disciplines and powerful knowledge (Young, 2007), content that cannot be learnt easily elsewhere. This content is a mix of skills and knowledge. I argue that there are limits on domains in large group projects, as not everyone gets to question the text in the same way, suggesting that not all parts of media literacy theory (Buckingham, 2003) would apply to all individuals making a digital media product. I argue that pedagogy involves surplus attention (Csikszentmihalyi, 2013), with students being able to accept failure and take risks (Robinson, 2011). Creative pedagogy is best practiced in environments with open ended project based learning, where students are working with each other to simulate the environment of professional practice (e.g. Thomson, Hall, Jones, & Sefton-Green, 2012). I cover Papert and Harel’s (1991) *constructionism* looking at the value of producing public artefacts that are validated by other people, making links with Csikszentmihalyi’s (2013) concept of *field*, and finding parallels with the media literacy of *audience* (Buckingham, 2003). Finally, for this section, I cover assessment, outlining the conflicts between the constraints that support creativity and those that undermine it, as well as the conflict between assessing creative thinking and the *domain* for creativity (e.g. Robinson, 2011). I again make links with Csikszentmihalyi’s (2013) concept of *field*, talking about the value of getting others to validate creative outputs.

Secondly, I outline *3Dcamp*, the 3D animation summer camp that is the focus of this thesis. Based on my knowledge of the camp, being one of the camp’s ‘Directors’, I outline the curriculum structure and the reasoning behind the content, pedagogy and curriculum. I argue that a model of student selection based on application using portfolios leads to better engagement and student intrinsic motivation (Thompson, 2013) than models that accepts all applications or where students have had to pay for places. The team based model is outlined showing how it attempts to mimic the normal practice of industry, a key concept within creative pedagogy (Thomson et al., 2012). The course is limited in its explicit content, preferring to provide individual level support, as such content for each student varies by their need and their role. I argue that the camp is delivering *powerful knowledge* (Young, 2007), knowledge that is not freely available to students in their everyday lives and will allow them to critique the world, by better understanding how things they consume are created. Finally, for this section, I cover the lack of an explicit global assessment model within 3Dcamp, explaining how students are setting their own individual targets. I argue that this might support the creative process by not setting one team against another and not tying students to any particular assessment rubric that would then influence the films they were making.

Thirdly, I outline how the 3Dcamps map to the computational thinking concepts of abstraction, decomposition, algorithms, generalizations, evaluation and automation (e.g. Selby & Woollard, 2013). I demonstrate how each of these concepts can be seen in the development of 3D animations.

4.1 Curriculum: Content

I start by trying to outline the purpose and content of a digitally creative curriculum. Young (2007) argues that schools are there to deliver 'powerful knowledge', that is specialist knowledge that we cannot expect students to gain easily from their own families and communities. This links to the systems model of creativity, where to be creative one should be utilising their understanding of the *domain* of knowledge behind a particular pursuit (Csikszentmihalyi, 2013). To be creative is to master, and potentially increase, the knowledge of a *domain*. The first step for doing this is to understand the existing knowledge, in our case the knowledge involved in the creation of 3D digital films, which is a mix of computing and media literacy. Where access to this knowledge is limited, e.g. by lack of school curriculum, or lack of parental support, then the curriculum of a 3D animation summer school should provide skills and knowledge not easily available elsewhere, that is it should provide students with *powerful* knowledge. However, a focus on content can be counter-productive to creativity, when it is at the expense of a "depth of understanding and breadth of application" (Seltzer & Bentley, 1999, p. 80).

Examples of university level 3D animation curricula show the conflict between the need to cover technical topics and skills, versus the need to provide realistic production environments where students can learn (Aoki et al., 2017). Burn & Durran (2007) argue that creative production is central to the learning of media and outlines that the broader range of skills and knowledge encompassed by media literacy should be added to the technical skills needed for production. It is the link between skills and the "critical knowledge required for communication within the wider culture" (Sefton-Green, 1999, p. 151) that needs to be the focus. Whilst the output of a 3D animation course might be a short 3D animated film, Robinson (2011) argues that "The educational value of creative work lies as much on the process of conceptual development, as in the creation of the final product." (p.278), and any content of a curriculum should be geared towards enabling the process of creation, rather than the end product.

Buckingham (2003) suggests a three part model for media education: teaching existing knowledge in the domain, allowing students to generalise from existing knowledge, and getting students to question and extend existing knowledge. Henley (2012) offers a similar model for cultural education, which offers access to a broad range of thought and creativity beyond that which a student would normally receive: analytical and critical skills to engage with this thought and creativity, and the skills to participate. This skill set includes skills to create and collaborate, and the tools necessary for students "to create new culture for themselves" (ibid. p.15). Whilst the learning of specific domains of knowledge is important, Seltzer & Bentley (1999) argue that creativity is fostered by knowledge of a range of disciplines and the intermixing of these domains. If the focus here is computing and media, what else might be helpful?

Having a focus on the close attention to detail and rigorous questioning of a media text is a core part to media literacy (e.g. Buckingham, 2003). Looking at a curriculum for a 3D animation camp, textual analysis would certainly fit into the role of a Director involved in making a 3D animation. But this role might not be applicable to other creators in a film making team whose role is largely around production. For example a 3D modeller might be given a task to create a hat from concept art. This role is technically difficult and might take up a considerable amount of time, but it might also be shielded from production decisions around camera angles, lighting, narrative and shot length. A curriculum might aim to cover the three part model of Buckingham (2003), but the implementation of the realistic production environment might not allow all students to utilise the full range of media literacy skills that they have learnt about, if the realistic production environment is to match the model seen in industry (e.g. that described by Whitehurst, 2018).

Another element of being creative is having the correct resources to work with. This manifests itself through individuals having surplus wealth and surplus time (Vygotsky, 2004). In the case of 3D animation the correct resources link to the use of the right software and hardware, as well as the allocation of time in which students can create. A 3D animation course should include software and hardware that allow students to express themselves fully, maybe offering tools that would not be accessible to students outside the course. Not only does the powerful knowledge of Young (2007) manifests itself through the ideas and skills that can be given to a student, but also through the tools on which these ideas and skills can be exercised.

Now I have outlined the idea of creative content, I turn to defining creative pedagogy, i.e. the methods of teaching a creative curriculum.

4.2 Curriculum: Pedagogy

There are multiple definitions of pedagogy including relationships, learning environments, rules and culture; for Thomson et al. (2012), creative pedagogy is one where we teach ‘habits of mind’ and ways of thinking, doing and being. A creative pedagogy is one that allows students to take risks in their work, to accept failure and to recover from it (Robinson, 2011; Seltzer & Bentley, 1999). Creative pedagogy might be at odds with a content based curriculum where the heavily structured schemes of work, learning objectives and lesson timings may result in a situation where “teachers and students may stop thinking for themselves and exploring new ideas, potentially risky ideas” (Steers, 2013, p. 167). To be creative involves having “surplus attention available” (Csikszentmihalyi, 2013, p. 8) or “time flexibility” (Thomson et al., 2012), clearly an overly busy curriculum would keep people too busy to provide this.

Baillie (2006) describe four stages to a creative process: preparation - where time is spent defining the problem or the question; generation - where you move beyond immediate patterns of thought and start to form new ideas; incubation - not dismissing ideas too quickly, leaving ideas then coming back to them; and evaluation - ideas are analysed, sorted and ranked. Techniques to support ideation include brainstorming, limiting the size of teams and assigning clear roles in group work (Thompson, 2013).

Seltzer & Bentley (1999) encourage project based learning for creative computing, with a combination of doing, thinking and knowing, with real world outcomes. This has clear parallels in computing pedagogy with *constructionism* (Papert & Harel, 1991 covered below), where students are seen to be best engaged with their learning when making digital artefacts that have meaning to themselves and the world around them, i.e. real world outcomes. Thomson et al. (2012) argue that creative pedagogy involves the recreation of professional practices in the learning environment, e.g. this is not just about projects, but about projects that replicate the environment of a professional maker.

Any tasks set should have the correct balance of challenge matched to the skillset of the maker (Seltzer & Bentley, 1999). Giving students tasks that are too far beyond their skillset and knowledge may leave them bewildered, giving them something too easy may leave them bored. Finding a student’s *zone of proximal development* (Vygotsky, 1978 cited in Chaiklin, 2003) helps provide the best scenario for creativity, where students have the skills and resources to attempt tasks that expand their current knowledge and skillset, with suitable guidance. Tasks set should also be open enough for students to bring their own interpretations into play; giving narrow or closed tasks can stifle creative expression; students should be able to make real choices about their actions (Seltzer & Bentley, 1999; Thomson et al., 2012).

Creative environments are those that allow people to work with each other (Seltzer & Bentley, 1999). This links in with the *field* from the system's model of creativity (Csikszentmihalyi, 1999) where students who are interacting with other students are both learning skills and knowledge from others, but also starting to know the people who will help verify their creative actions, either accepting a digital artefact as being creative in some way, or rejecting the work. However, it isn't as easy as just speaking with other people, interactions have to be built on trust, where people are comfortable with giving and receiving feedback. Negative criticism should be avoided and team work encouraged, attempts should be made to nurture people's confidence in taking risks (Robinson, 2011). The process of giving good feedback doesn't come naturally to everyone and work might be done to train team members in feeding back to each other (Thompson, 2013).

Creativity is best supported when students have intrinsic motivation, e.g. interest, enjoyment, setting own targets; in fact creativity can suffer under extrinsic motivation (Beghetto, 2010; Thompson, 2013), e.g. the promise of a given return such as money or exam grades. Vygotsky (2004) argues that as well as the need for a final product based in reality, "all forms of creative imagination include affective elements" (Ribot (1904) quote in ibid. p.19). This means that we are emotionally engaged with the output of our imaginations, they aren't just sterile products of the workings of the mind, but outputs that come attached with feelings and sentiments. This makes it even more important that interactions with other people are courteous and supportive.

Robinson (2011) describes creative environments as having internal culture, the tacit rules and informal codes that regulate behaviours within a group, or habits, being supported by habitats, the creative physical environment in which a person works. Thompson (2013) argues that creative spaces should have both 'caves' and 'commons', places where people can retire to work independently and areas where they can work with other people.

Pedagogies and curriculum within formal education might not match those experienced by students in informal education, such as maker communities that are online. Buckingham (2003) is concerned that teacher led education in school will become peripheral to student's lives and that a mismatch of pedagogies will lead to disaffection amongst school children.

Having described research about creative pedagogy I now look specifically at *constructionism* a pedagogy often linked to the use of computers.

4.2.1 Constructionism

This idea of "making" is accompanied by a learning theory linked closely to computing called *constructionism*, known most simply as "learning through making" (Ackermann, 2004). This pedagogy is built on the theory of constructivism, in the sense that, that learners build their own cognitive tools and construct their own realities based on how new experiences relate to existing knowledge (Papert & Harel, 1991). In addition to this, the focus of constructionism is for the learner to be "consciously engaged in constructing a public entity" (Papert & Harel, 1991). This takes the concept beyond learning through doing, introducing a social aspect to the work, where the work isn't just a finished product, but also the process of creating and the potential discussions around the creation once finished. The pressure on an individual to convey their work to others helps with the reinforcement of learning, and the "end product must be *shared*" (Harel, 2001).

Examples of constructionism might be a student making a video for others to see online, or programming an application that others can share. The most prominent example of constructionism currently is the MIT Scratch programming website,[23] which is built on constructionist ideas (Maloney, Resnick, Rusk, Silverman, & Eastmond, 2010). This website allows students to create their own animations, games and applications using a simple block based programming language. To link in with the constructionist ideal, the programs that are developed on this platform are available for others to access, comment on and favourite. Taking this one step further any project on the website can have its code based explored, allowing others to see the exact programming blocks that were used to create the application, both allowing the viewer to learn from another project, but also reuse and adapt the code for their own purposes.

Links have been made between constructionism and creativity, that constructionism allows for an "optimal learning environment" for creativity to happen (Ackermann, Gauntlett, & Weckstrom, 2009, p. 59). Using the systems model of creativity (Csikszentmihalyi, 2013), I now suggest how constructionism maps to the concepts of field, domain and person. Constructionism's focus on creating a *public artefact* (Papert & Harel, 1991) injects the idea of an audience into the work; in this way the maker becomes involved with the people who make up the field, and depending on the platform used the maker might receive feedback and accolades that are deemed important to the field; this can also be seen as a form of symbolic capital (Bourdieu, 1986). The domain component of creativity is addressed by the creation of the artefact. However, the scope of a student's interaction with the domain may be limited by the scope of the project they are undertaking, the teacher's ability to support the student, the support provided for the platform used, or even the limitations of the platform itself. For example a student might be given the project to make a static 2D poster, thus limiting the scope of the tools that a student might reasonably use. Even when undertaking a more advanced project

[23] https://scratch.mit.edu/

in Scratch, the Scratch language does not allow for the use of *classes* or returned values from functions, both core domain concepts in most common programming languages. I discuss the benefits of different software, in the software section below. Additionally, open-ended design projects with content agnosticism can lead to inauthentic authorial engagement through where students might be inclined to rehash commercial ideas and content rather than doing something new (Lachney, Babbitt, & Eglash, 2016). As noted above, creativity is supported by the use of limitations, you cannot create from nothing and attempts to do so in this area appear to limit student outcomes to their immediate knowledge. Constructionist goals should be set within suitable frameworks.

Constructionism is an established way of teaching computing (Garneli et al., 2015) and similarities can be drawn between constructionist principles and models seen in Media education and concepts of Media literacy. Media literacy (Buckingham, 2003, p. 199) states the importance of having a real audience, the constructionist approach insists that artefacts are a "public entity" (Papert & Harel, 1991), meaning that the creation of an artefact will be undertaken with students fully engaged with their idea of the audience(s) of their product. Additionally, practical work should be recursive: "the product should not be seen as the end of the process … [but] a starting point for reflection or redrafting, and the basis for future work" (Buckingham et al., 1995, p. 226), this matches much of the remix/reuse conceptualisation of constructionism, and can be taken beyond the development of an end goal to the realisation that a film can be remixed into other films.

The similarities between constructionism and media education suggest that constructionism is a valid approach to teaching digital skills such as 3D animation. I now turn to defining how a creative curriculum might be assessed.

4.3 Curriculum: Assessment

What to assess and how to assess it can have a profound impact on creativity. Sefton-Green (2000) argues that trying to quantify creativity stifles the creative process as it leads the maker along a path of creation that focuses on what will be assessed rather than what they themselves feel is best. Beghetto (2010) notes that when testing is considered the most important pedagogical goal for a teacher, then testing drives instruction.

However, Robinson (2011) argues that creativity is best achieved within constraints, where rules are used to define the boundaries of what can be made and how it should be made. For example, it might be argued that a creative football game would need rules around handling the ball and how a goal can be scored; someone picking up the ball and running it into the corner flag would probably not be considered creative as it breaks the rules and fails to achieve the goal of the game, which is to get the ball into the net. Burn & Durran (2007) support the view that assessing creativity can be bad for the creative process, but also argue that we need an assessment model to use to make sure that we are doing the right thing. Making the rules of the creative process clear and how creativity will be assessed is important for getting students to act creatively: "Unless teachers also include expectations for creativity in their assignments and assessments, then the message is quite clear: Creativity doesn't matter." (Beghetto, 2010, p. p453). What form these expectations take is important as knowledge of assessment rubric can often lead students to taking the safer options and avoiding experimentation (Robinson, 2011, p. 278).

If creativity is to be assessed, then what parts of the creative process and product should be assessed? Grigorenko, Jarvin, Tan, & Sternberg (2008) argue that the creativity within a domain can be "determined both by the demonstrated mastery of the skill of creativity (i.e., creativity proficiency level) as well as by the demonstrated mastery of the content of the domain (i.e., the knowledge of literature or math)" (p.297). Conti, Coon, & Amabile (1996) offer a similar model where they separate "domain relevant skills" and "creativity relevant skills" (p.385), arguing that both are necessary to be creative. For example, you might be an excellent divergent thinker (a creativity relevant skill), but without any knowledge of Newtonian laws (a domain relevant skill) you might not make a very creative physicist.

Creative proficiency is often tested through assessment for divergent thinking (Baer, 2010), where people are expected to explore multiple possible solutions to problems, as opposed to convergent thinking where they settle on, and maybe develop, one solution. The work of Bennett, Koh, & Repenning (2013) on assessing creativity for computational thinking looked at divergence in attributes of student's computer games. For example, they looked at how much the programming used in a student's game differed from the given example program. Students were still being expected to create working games, so divergence was within the framework of a runnable program.

The mastery of the content of the domain is also important and this involves the particular knowledge and skillset of an area of endeavour. And whilst it is clear that to assess creativity some evaluation of a student's grasp of the domain is necessary, within digital creativity the scope of the domain is contested. Where more traditional media is being created through digital means, e.g. film editing, Sefton-Green (1999) questions whether the assessment model should be based on the traditional subject area or the new digital interpretation; the risk here is to judge creative work against rubrics that are outdated. He goes on to ask "Do we evaluate students' grasp of authoring packages or their capacity to *imagine* in the new medium?" (p.149), and whether assessment models should incorporate meta skills such as teamwork and decision making.

If we accept the systems model of creativity (Csikszentmihalyi, 2013) we can argue that the *field* is also important for the creative process. Creativity takes place within a social setting with the approval of the field helping to create societal levels of creativity: "what is creative is a matter of consensual assessment" (Sternberg & Kaufman, 2010, p. 467). It follows that assessment of creativity through the judgement of peers is a natural way of judging the creative work (Robinson, 2011), or that the manipulation of the social setting itself by the creator could also be open to assessment.

4.4 A 3D animation summer camp

I now describe the 3D animation summer camp that this research project is based upon. The functioning of this camp was built on much of the creativity research described above and I will link the theory to the implementation whilst outlining the functioning of the camp. Sefton-Green (2014) described 3Dcamp as one of the few examples he saw of an event that "genuinely combine[s] creative and digital learning", and the aim here is to show how the camp maps to the body of research behind creative curricula. It is also worth noting that 3Dcamp was established in 2012 to correct the mistakes seen in other digital summer schools, which were often highly prescriptive and too often ineffective in providing aspiration intervention for young aspiring digital makers.

The meta analysis of aspiration research by Higgins et al. (2016) shows that students don't generally lack aspirations, but they do lack the knowledge and skills required to fulfill these aspirations. Even where aspirations are raised, this isn't necessarily accompanied by any improvement in learning, unless academic support is provided. Based on this, the summer camp aimed to focus on delivering domain specific knowledge and skills. Additionally the camp structure aimed to give students a significant experience of 3D creation, by taking place across seven days, rather than the one or two days of other contemporary digital courses.

There are many examples of outreach events for film and VFX, such as those offered by the BFI[24] and IntoFilm.[25] However, there are no camps for 3D *digital* animation in the UK outside the non-free and games focused firetech camps that rely heavily on reusing 3D assets.[26] Whilst other outreach events might be focused on raising student aspirations to work in the film, animation and VFX industries,[27] young people generally have quite high aspirations and poor results are not due to a lack of aspiration, but a lack of knowledge and skills in the areas that students want to succeed (Higgins et al., 2016). 3Dcamp stands out as currently being the only 3D *digital* animation camp in the UK, if not the world.

[24]https://www.bfi.org.uk/education-research/5-19-film-education-scheme-2013-2017/bfi-film-academy-scheme
[25]https://www.intofilm.org/
[26]https://www.firetechcamp.com/course/3d-game-development-unity/
[27]e.g. http://www.accessvfx.org/events/

4.4.1 Brief overview

3Dcamp is a non-profit organisation founded to promote digital art amongst pre-university students. The target age for students is 14-18 (although younger students have been accepted depending on their ability, skillset & maturity). It runs free seven day animation camps where students experience every part of production, from scriptwriting, modelling and animation, through to final première of their film in front of an audience of their peers, family, friends and industry. They aren't allowed to reuse assets from elsewhere and are forced to plan and create a full film from scratch. The focus on the production processes involved with film creation, rather than making sure an end product is produced, is supportive of the idea that the process might be more important to creative production than the product itself (Robinson, 2011). Additionally, the expectation that students are going to create a film, a public artefact to be shared with others, links in with the constructionist computing pedagogy, which argues that learning best takes place when students are working on something that will be shared with others (Papert & Harel, 1991). Allowing students to pick their own stories links with constructivist theory and aims to increase student engagement as students are involved with the development of a product over which they have complete ownership, supporting intrinsic motivation amongst students, which is seen as a better driving force than extrinsic factors such as paying the students for their work (Thompson, 2013).

One of the original reasons for the creation of 3Dcamp was that there were no easily accessible internships available for young 3D digital artists, so there was a need to create a model to provide industry experience for students without having to put students into the workplace. This meant an attempt to adopt an industry/animation studio like model throughout. With realistic recruitment methods, i.e. students applying through a portfolio; the use of standard management practices, i.e. a director and producer being elected from amongst the students who then took on management responsibilities; following the pipeline model of development (e.g. Whitehurst, 2018); the structuring of work to follow industry practice i.e. the use of break out meetings and 'dailies' where work is shared and problems tabled to the rest of the group; the optional use of extreme work patterns, i.e. many students stay into the evening, some of them also arrive early; and free food and sweets. 3Dcamp provides access to high-end computers with dedicated graphics cards and specialist software, something that many students won't have at home. 3Dcamp uses Blender, an industry standard 3D creation tool. Students also have access to a 'render farm', a combination of software and thousands of computers that speeds up the process of creating the final shots of a film, also known as rendering. A special asset management system has been created where directors and producers can have an overview and control of tasks related to the creation of a film.

By experiencing what it is to work in a 'studio' students will then be better placed to make informed decisions about whether working in the 3D digital arts industry is the sort of job they would like to do, serving both as a form of aspiration intervention, but also a form of domain acquisition to act on any changes in aspiration. A brief outline of the structure of 3Dcamp is outlined in Table 4.1:

Table 4.1: Brief outline of a 3Dcamp 3D animation camp

Day	Activity
Precourse	
April to July	Students work on a portfolio to get on the course. This portfolio shows that they have mastered the basics of Blender as well as demonstrating any other skills they might have. They will be given feedback to respond to from 3Dcamp staff and depending on their response they will be admitted to the course.
Wednesday	Icebreakers are done as they arrive to get them working as a team; this includes a showcase of application portfolios. A talk is given to take them through the script development / storyboarding process. An intense script development and storyboarding session then occurs, where they plan out the entire animation they are going to make. If they finish early they can be taken to the computer room to start. By the end of the day the students will have planned their entire film. We keep our meddling to a minimum – it really is their own script, their own ideas and their own story.
Thursday	The day starts with a talk on using Blender for a team project, including the concepts of linking (splitting shot into models, sets, animations), shared drives, directory structures and asset lists. As the students now know each other the team leaders are chosen after the team project talk; these students then start to organise 'daily' meetings. An asset list is made by the producer, so assets can be ticked off as they are created, jobs start to be assigned by the producer to other team members. The entire short film is roughed out as an animatic by the director, so they can watch it end to end (Using the scanned in storyboard, and rough animation as appropriate). If any work remains from Wednesday, e.g. concept art, or storyboarding, a small team should be created to finish it in parallel

Day	Activity
Friday	At this point most of the props will have been started and the sets will be coming together. The director will be keeping a close eye on the look of the assets being made; the producer will be allocating students to help each other and trying to match tasks to the skillset of individual students. One or two students on each team will be siloed off creating characters, as this is one of the most time consuming roles.
Weekend	Whilst the weekend is officially a break many students continue to work on either sharpening their skills or on their film.
Monday	By the end of the day all of the characters should be usable and students who have finished creating props and sets will be shifted to practicing animations with the character models
Tuesday	Character animation becomes the key focus. An industry visit might occur, or industry representatives might visit the camp to give feedback on the student work. Several shots should be completed and added to the animatic so that feedback can be given on the film.
Wednesday	By the end of the day all of the shots are done, so they can be sent to the render farm overnight and be available the following day. The producer and director should be prioritising shots to be polished and utilising their team's skill sets. Several students might be allocated the task of finding and making sounds for the film

Day	Activity
Thursday	The director should add all the finished shots to the animatic and all groups will watch the first draft of each film, giving detailed feedback to the producers and the directors. Final changes should be prioritised at this stage and the day is spent compositing and polishing the final film. Some students will start to become free as their 3D animation roles end, they will either be added to the sound creation role, or set other less important tasks such as the creation of the credits. The final steps to complete the film only involve a few students the remaining students prepare a presentation to be given before the short is shown and/or taken for drawing classes. In the evening a première is held where the students give their presentations and show their short to an audience of parents, industry mentors and dignitaries.

4.4.2 Application process

3Dcamp has attempted to create its own application process, distinct from those seen in other computer science and digital art summer courses, e.g. Young Rewired State accepted any student who was interested in attending their events: “If you are aged 18 or under and you live in the UK, you’ve made it!”[28]. My own experience has witnessed many students entering large scale computing summer schools, on one occasion winning a national award. I have also seen many examples of students signing up to attend these schools and dropping out at the last moment as they lacked the incentive to attend. The general form of a summer school application process ranges from acceptance of anyone of the correct age, to potential positive discrimination for gender and minority groups (e.g. courses specifically run for minority groups). Courses vary between paid and free models. The application process for 3Dcamp has been constructed to incentivise students to attend the course by getting them to apply with their own work.

Attendance at 3Dcamp is free with the aim of alleviating any financial barriers to young people taking part. There is a focus on engaging students from poorer backgrounds with outreach events in deprived schools in the months preceding the course. The intake is diverse in terms of socio-economic, gender, and ethnic groupings. In 2013, 80% of the students would not have been able to attend the course if it was charged for. Similar courses cost up to £1350 and students are expected to bring their own food and computing equipment,[29] both of which are provided for free at 3Dcamp.

[28] https://web.archive.org/web/20150706225856/http://festival.yrs.io/register/participant
[29] https://www.firetechcamp.com/course/3d-game-development-unity/

To get a place on the camp, students have to demonstrate that they have mastered the basics of Blender through completing some free online simple tutorials.[30] Once a student completes their portfolio they send it to the 3Dcamp team who give them feedback, and depending on how they respond to the feedback, they will secure a place on the camp. This serves four purposes. First it makes sure that students attending can work with the software that 3Dcamp uses, meaning that when they join the course they can concentrate on creating with Blender and making films rather than teaching themselves the basics. This also means that the course has to dedicate less time to upskilling students, leaving more time for students to make their films and making it more likely that they will have the 'surplus attention' that supports creativity (Csikszentmihalyi, 2013). Second, it gives students real experience of using industry standard tools, filtering out those who don't take to it and making sure that those who do attend are capable of the work. Third, it creates intrinsic student buy-in for the event, meaning they are less likely to drop out as they have 'paid' for the event with their own time and effort, not their parent's money. This intrinsic buy-in is important as it is a better motivator for students wanting to be creative than extrinsic motivation (Thompson, 2013). For example a student whose mother had paid for their attendance might attend each day and pay lip service to the event for fear of upsetting their mother (and the extrinsic punishment they might receive), whilst a student who had earnt their way onto the course through hard work would and discovering what they were capable of would want to increase knowledge and participate fully (intrinsic motivation). Fourth, it allows the 3Dcamp team to balance teams in terms of skill set, from looking at the portfolios. For example, each team might have an advanced modeler, an animator, a rigger, a concept artist and 5 students with generalist skills. This "motley crew" allows for skill sets to complement each other (Thompson, 2013). However, there are issues with this application model, students from middle class backgrounds are more likely to have support for digital creativity at home (Sefton-Green & Brown, 2014), they are also more likely to have computers at home (Ofcom, 2017). This means that working class students are less likely to complete independent application tasks such as the one described above, even when the software and support materials are free. To alleviate this issue 3Dcamp attempts to recruit students through their schools, relying on school teachers to support students in their applications and provide computers on which students can create their portfolios. This model isn't perfect school outreach events have been conducted by the 3Dcamp team, focusing on schools that serve poorer communities.

The application process involves two stages: a declaration of interest by filling in an online form, followed, a few weeks later, by a request for a full application showing their work. All videos and tutorials suggested to students during the application process are also free and allow students to learn well beyond the basics if

[30]e.g. https://projects.raspberrypi.org/en/projects?software[]=blender

they wish. The number of students who declared an interest in attending was four times higher than those who completed their application. 3Dcamp speculate that many of those dropping out found that they didn't enjoy 3D animation, or were put off by the commitment necessary to complete the tutorials. The first case is a positive outcome for the student, as they have real experience of using an industry standard tool and can now make a more informed choice as to their futures. The second case helps 3Dcamp filter out students who might not cope with the commitment required by the event. This model is an attempt at aspiration intervention (Higgins et al., 2016), not just helping raise aspirations, but also providing skills necessary to achieve the aspirations and redirecting aspirations of students who feel themselves unsuited to 3D animation.

Getting students to create portfolios with industry standard software has several issues. Industry standard 3D animation software is often expensive, not multiplatform and requires high powered computers to run (Kemp, 2016). The choice of Blender is essential here in getting students started and making this part of the process accessible. Blender is open source software, meaning that it is free for students to use and it runs on multiple operating systems. Additionally, Blender runs on far less powerful computer systems than other similar function software. This means that students from all backgrounds can run it, at school, at home or at a local library. Choosing commercial software would seriously limit the number of students who could complete their applications.

Now that I have outlined how students successfully gain a place on the course I move on to describing the activities that take place during 3Dcamp and the roles needed to perform them.

4.4.3 Ideation

On the first day of the event students are placed into their teams and start working on creating the ideas and stories behind their films. This ideation stage involves all students coming up with their own ideas, then sharing and refining them. Thompson (2013) argues that we need to avoid being fixated on the first idea that someone comes up with as often this will stop better ideas developing. This matches other creativity research that argues that creativity is best achieved when people are producing multiple outputs, selecting the one that performs best (Richards, 2010).

The topic of the film is defined by a lyric from a rock or pop tune, normally from the 1980s. These topics are generally ambiguous, easily accessible to the 3Dcamp team, and hopefully not known by the students, meaning students are less likely to settle on their own preconceived ideas. For example, "a better future" by David Bowie was unknown by the students and offered an almost unlimited number of interpretations . This lyric was shared with the students who then created short ideas through brainstorming (Osborn, 1963). Following the rules of Adams (1980), students are first encouraged to produce as many ideas as possible, without stopping to explain or criticise. They do this alone, writing anything from a theme, to a character, a location, an object, an action or a line of dialog. This helps avoid the “primacy effect” where students might latch onto the first idea they come across (Thompson, 2013, p. 16). Fifteen minutes is dedicated to this task, after which students spend twenty minutes sharing their ideas with each other. Students are then encouraged to borrow ideas from other students on the course and develop a very short story in bullet point form. ‘Speed dating’ is then performed where they have to explain their film, receive feedback, listen to another short film description and give feedback, then swap partners. All students are then asked to improve their ideas by writing up a fuller description building on the feedback they have received. This helps avoid fixation on any particular person in the group, as all students are writing a script. Students then present their scripts to the rest of the group and vote on two to develop further. They develop the script in groups of four or five for a further 30 minutes. Finally they present their whole story idea in one minute to the whole cohort, including the staff, who then vote anonymously on which film should be made. As such, a team doesn’t get the final say on what they make, the choice is made by the rest of the group. This is done to support team cohesion, i.e. they can’t blame other team members for not picking their favourite, and to build on systems model of creativity, where the field, i.e. their peers, help judge the most creative film option and the one most likely to please the potential audience (e.g. as argued by Robinson, 2011).

Once a film has been picked, the whole team works on creating the script, storyboard and concept art. By the end of the first day the whole film can be seen as a series of drawn images in sequence. At the beginning of the second day this sequence is put into the Blender video editor to be watched as an animatic. Whilst things might change slightly, generally the story agreed on the first day is the one seen at the premiere six working days later.

4.4.4 Teams

3Dcamp is a team based course. Whilst it is recognised that “groups are distinctly less productive than individuals when it comes to creative performance” (Thompson, 2013, p. 51), 3Dcamp aims to mimic an industry team environment, providing students with experience of what is to work in the 3D animation profession (Thomson et al., 2012). It also recognises that the work to produce a short animated film would be beyond the capabilities of one person within a seven day period.

The students are divided into groups of nine with one student being tasked with the director role (the artistic lead) and one or more students being tasked with the role of producer (organising tasks for the rest of the team). More specifically:

Director: Has final say on all creative decisions. They are also responsible for consistency, i.e. making sure all of the shots feel like they come from the same world and making sure the story is told. This is often the originator of the story, but this is not always so. They put together the animatic on day one comprising the drawn storyboard shots. As the week progresses each drawn storyboard shot is replaced by film footage, until all shots are replaced and they have the working film.

Producer: Responsible for making sure that the work gets done. They keep an eye on the asset list stored in the asset management system, and make sure everything will be done in time. They normally allocate tasks to students that match student skill sets.

People without group facilitation skills, who are facilitating groups can often do more harm than good (Thompson, 2013), so the above roles are clearly specified and each team has a member of staff to support and step in if things go wrong. These roles are further explained in *Staff and industry*, below.

There are several issues around team working and creativity. *Free riders*, people who do little work but try to take all the reward, are more likely to appear in larger groups (ibid.) Controlling free riders is important for group cohesion and getting work done. By selecting teams to have balanced sets of student abilities, and clearly assigning roles and tasks to group members, then free riders are less likely to appear. This is largely achieved through the application process where staff balance teams based on student entry portfolios, and through the role of the Producer, who keeps track of tasks and matches people to their most suited task. Having meaningful tasks is another way to discourage free riders, for example, one student might have a limited skillset and be assigned to making rocks, but knowing that these rocks are important for the overall film and have value to their teammates will make them more likely to stay focused. Another way to prevent free riders and students coasting is through regular performance reviews (Thompson, 2013). At 3Dcamp these are achieved through the use of 'dailies', whole team meetings that happen one or more times each day where the Director and Producer check up on the progress of each team member and give feedback on how the film is going. Communication issues also arise with larger teams (ibid.), 3Dcamp makes use of an asset manager, an online database of tasks to be completed with details on who is completing them, to structure student work loads and help structure communication between students. For example, the settings to say whether an asset is "polished" has other states to imply that the asset still needs work, this helps reinforce feedback that might only have been given verbally. Dailies are also used to help give teams time each day to communicate with each other, away from the noisy work room.

Other attempts to increase group cohesion include the daily lunch run, where students are given funds to buy food, often choosing to buy things together. In the final few days students often task and trust each other with buying food.

Team working environments aren't always conducive to creativity (DeMarco & Lister, 1985). Unfortunately 3Dcamp lacks the space to give students quiet areas to work on their own. The working environment is one large shared space. However, students are encouraged to listen to music and work independently when necessary.

Having described the how the students function within teams, I now outline the roles of the staff members who help facilitate the running of the camp.

4.4.5 Staff and industry

3Dcamp requires a very specialist set of people to run it. Programming camps can quite easily find amateur programmers in their local area as programming skills are more common in the general population; the 3D animation industry takes up much more of a niche, and finding suitable technical support has proven difficult. The staff running the course and the visiting industry mentors help build the *field* (Csikszentmihalyi, 2013) of support around the students, providing a bridge between the work on the course and decisions about future careers and education, through mentorship and advice. In addition they support students in accessing their zone of proximal development, acting as bridges between what students can do unaided and what they can do with the support of others (Chaiklin, 2003), for example student might be very good at modelling trees, but a member of staff might aid them in quickly creating a forest. I will now outline the different staff members in a 3Dcamp camp:

Technical Expert: the person who knows the Blender software inside out and who is able to answer difficult technical questions. The nature of the selection process for the course means that questions will be posed that are beyond an amateur animator. "How do I rig a realistic fishing rod" as opposed to "how do I make a fence", the technical expert needs to be able to answer this.

Teacher organiser: handles registration of the students, chasing students who are late, organising breaks and food and delivery of the taught sessions. Their main role is making sure that team cohesion is maintained throughout the course, helping allocate support and giving advice to struggling directors and producers.

Student helpers: each team has a dedicated student helper. These are students who have been through the course before so can lend their advice to directors and producers, as well as helping with minor technical issues that students might have.

Industry: 3Dcamp provides a link between the industry and students, giving them access to cutting edge techniques and suitable advice. This has involved working with a range of visual effects, film and animation companies. Where possible industry mentors are encouraged to attend 3Dcamp camps to provide hands on assistance and advice, rather than delivering aspirational talks. This links in with the research on aspiration intervention, focusing such work on increasing student skill sets whilst at the same time raising their aspirations (Higgins et al., 2016).

Returning to our ideas of a creative curriculum, I now outline the content, pedagogy and assessment present in 3Dcamp, linking its structure back to literature on creativity.

4.4.6 3Dcamp Content

3Dcamp has a limited explicit curriculum, mainly focusing on the soft skills needed to work as a studio. Students are only allowed on to the course once they have submitted a portfolio, which will have taught them the basics. This means that the event is then targeted to support individual student learning needs rather than forcing a particular outcome for all. Examples of this personal curriculum are: students wanting to learn how to add the bones to a crab so it can be animated, other students wanting to make realistic waves breaking on the sand, and a student wanting to learn how to automatically make a forest using a particle physics simulation.

During the course there are only two specific lectures. The first on ideation and story creation, and the second covering how to work with Blender and the asset management system as part of a team. Part of this lecture involves the textual analysis of existing 3D animated films, giving students the skills to then critique other group's outputs and their own. This second lecture involves a short presentation then a seminar where students have to practice setting up and rendering shots whilst using the asset management system. This combination of media literacy and digital skills is in line with Buckingham et al. (1995) and Sefton-Green (2013), who argue that media creation crosses multiple knowledge domains. From the middle of the second day there is no longer any set curriculum and students are encouraged to help themselves through using online learning platforms, help each other through peer support, or seek the help of a staff member for any other outstanding problems. As such the official content of the course is limited and the skills learnt are specific to each student, the focus here is on creative production. This model is supported by Burn & Durran (2007) and who argue that media is best learnt through making. Getting data on the efficacy of this learning approach is difficult as there is no randomised controlled trial to compare the learning outcomes of a 3Dcamp course and an equivalent 7 days spent in school. However, students appear to be engaged and invested in their work, staying into the evenings and showing pride in their work.

The content of the application process, e.g. the suggested tutorials, aren't normally covered by students in schools, additionally, students bringing their own specific needs to the staff at the course, imply that there are problems that they haven't been able to solve independently. This suggests that the knowledge being delivered at 3Dcamp is *powerful knowledge* (Young, 2007), as it is both unavailable in a student's everyday life and impactful on their relationship with the world, i.e. it helps demystify the media materials that students consume.

Lasseter (1987) outlines how traditional animation techniques can be applied to 3D animation, and many of the skills you would see present in two filmmaking are also present at the summer camp. General expected content to be covered when making a 3D animated film is outlined in the support guide for 3Dcamp (Haines, 2017). This guide lists several technical areas. Including: modelling props and sets, rigging / weight painting, character design, animating, weight painting, compositing, optimising rendering and video file formats. Media literacy content is present, including scriptwriting, script analysis, the camera, shot types, storyboarding, concept art and genre. Several chapters are focused on creativity including *ideation*, *what is art?* and *failure*. With other chapters focusing on team working strategies including relationships, time management, dailies, asset management systems and the roles of producer, director and minion. Taking this book as an indication of the content of the course, it is clear that several different domains are being combined, in line with Seltzer & Bentley (1999) who argue that creativity is best fostered when a range of disciplines meet. The combination of media skills and technical skills, a healthy place for creativity to arise (Henley, 2012), are clearly outlined above. However, it should be noted again that the full range of skills do not apply to all students on the course, with some students focused on particular areas such as modelling or lighting, for much of the duration of the course. The content of 3Dcamp is centred around student needs and wants.

4.4.7 3Dcamp Pedagogy

The curriculum model of 3Dcamp is heavily practical, but it aims to give students a foundation in 3D animation skills so that they can gain a "more systematic understanding of how the media operate" (Buckingham, 2003, p. 181). It is intended as a first step in demystifying the technology that creates 3D animated media, readying the student to be critical of what they see. 3Dcamp attempts to use a creative pedagogy, in ways that are now described.

The lack of explicit content within the 3Dcamp curriculum allows more time for students to be focused on making and coming up with innovative solutions to problems (Steers, 2013). This lack of content can be seen as a good thing, as students are then able to focus on problems that interest them, either the ideas behind the film and/or the chance to work on creative outputs that they would like to make, e.g. students working on perfecting an animation, or building a beautiful set. This links to the idea of intrinsic motivation, where students are self motivated to tackle tasks, rather than being pushed into tasks by financially or other extrinsic rewards (Thompson, 2013). The structure of the course also allows students to be involved with making real films using real industry technologies. This links in with the idea of creativity best being fostered when students are involved with real world outcomes (e.g. Seltzer & Bentley, 1999). Constructionism (Papert & Harel, 1991) is an important part of 3Dcamp, where students are creating a tangible artefact, the film, for other people, the audience, with parents, friends, industry and peers are invited to the premiere of their film at the end of the seven days. The films are also uploaded onto youtube[31] where they become available for future portfolios aimed at getting into university, or just for anyone else to come and see. Pushing this concept further, the actual computer files used to make the films are shared online after the events, allowing others to see how the films themselves were made and remix the films for their own purposes.

Whilst this environment might appear suitable for giving students "surplus attention" (Csikszentmihalyi, 2013) and thus allowing them to focus on creative outputs, actual time available to students is very limited. Many students choose to stay late into the evening to finish work and shots and assets are sometimes dropped from finished film products due to running out of time.

Whilst students are encouraged to explore new areas and develop new solutions, matching the idea of creativity being brought about through risk taking (Robinson, 2011). Limitations around the number of characters and the type of films produced are encouraged by the staff. For example, students are encouraged not to use more than three characters, not more than three sets, to avoid complex physics simulations, to avoid complex emotions, to tend towards cartoony rather than gritty and to "do a short film well than a long film badly!" (Haines & Kemp, 2017, p. 28). These suggestions act as invisible lines of force, pushing students into decisions they wouldn't have made otherwise. Factors that have to be considered by the 3Dcamp staff when suggesting limitations to student work involve time available, student skill sets, limited computing power and the given story key phrase in mind. If these limitations were not provided then it is likely that the students would be unable to finish their films. Building on the idea of balancing the task to the skillset (e.g. Seltzer & Bentley, 1999; Chaiklin, 2003), this adds the dimension of computing power, i.e. the best balance for creative output should also take into consideration the limitations of the tools at hand.

The students are encouraged to make every part of their 3D film, combining the components, made by different students to deliver meaning, a form of lamination of adjustable meaning making components (Burn, 2013). The film is made in a modular way allowing for distribution of work amongst team members and the individual development, testing and iteration of film components, an example of modular design seen in certain definitions of computational thinking (Bennett et al., 2013). The software used allows for deep remixability of the components of the final product, where (largely) any element may be adjusted at any time

[31] e.g. https://www.youtube.com/watch?v=uV8K7AWYnes

to change and improve meaning making. Students are actively encouraged to see their work as an iterative process, not a linear one (Buckingham et al., 1995). With 3D digital animation not only is the structure of the film malleable within the digital editing program, but each character's position, posture and hairstyle is also there to be manipulated, at any point. To give you an example of this in practice, many of the 2D cartoon adverts you see in supermarkets or on billboards are 3D animations 'flattened' during the rendering process. 3D is used by the creator, as the director of the project often changes their mind about the position and facing of the assets within a scene; to redraw the 2D models would take too much time.

Students are encouraged to seek support from each other and from online groups. For example if they are struggling to make a fence, they might find a tutorial that shows them how to do this. This links in with the fourth element of digital creativity defined by Sefton-Green (2013), where students take part in online communities to aid their learning.

Feedback is core to the course, and students are encouraged to give feedback on their own work, as well as feedback on another team's work. This is achieved through the director's and producer's day to day management. This links in with ideas of constructionism (Papert & Harel, 1991) with their peers serving as an audience for the public entity that they are making, both as the final audience, and as people to give feedback on the work as it is being produced. The *field* component of systems creativity (Csikszentmihalyi, 2013) is also present, not only through the other students on the course, but staff members and industry visitors providing feedback and validation for the creative work that the students are making.

4.4.8 3Dcamp Assessment

For a course attempting to simulate the skills required in a 3D animation studio, it would be inappropriate to assess student progress based on competencies in a *range* of technical areas. For example, if a student was particularly skilled at animation and did very little else, what they took from the event was just as valid as someone else who showed a broader but shallower range of skills.

Another way to assess the films might be through textual analysis, the close attention to detail and rigorous questioning of a media text, a common focus in media studies (Buckingham, 2003). Whilst this might be a good way of assessing the role of Director, this role isn't explicitly asked for in the rest of the team whose role is largely production. For example, a student might only be working on set design having been given a specification from the director, as such they have very little input on the timing of shots, the positioning of the camera and the actions taking place on the screen. All of this has an effect on the range of analysis techniques available to the researcher, as questions such as those around choice of style and genre might be absent from the available discourses of many students.

Another reason for focusing on skills rather than textual analysis for this age group, is that the medium of 3D digital art has a much higher entry bar for those people wanting to imagine new possibilities through the medium, and technical prowess influences student's ability to express themselves (Buckingham, 2003).

Other suggestions about judging the entirety of student films as the "best animation", "best models" or "best use of emotion", this would allow the course to encompass knowledge and skills from the different domains that make up 3D animation (as suggested by Sefton-Green, 2013). However, these forms of summative judgement have been strongly rejected by the 3Dcamp team, who want to encourage cooperation throughout the event between members of different teams. Putting students against each other in the pursuit of a prize might discourage peer support.

A lack of formal assessment might support creative outputs (e.g. Sefton-Green, 2000; Beghetto, 2010). But, as noted above, there are limitations set on the work that students produce, and whilst they aren't being given grades against these limitations, these limitations will be formatively assessed throughout the camp through conversations with 3Dcamp staff. The most important assessment for students might be self assessment, how did they do against their own self-set targets, and did they manage to make the film that they wanted to make within the constraints that they were given.

Now that the curriculum of 3Dcamp has been described, I move on to outlining the outputs from the camp.

4.4.9 3Dcamp Outcomes

3Dcamp was created to provide students with a significant life experience that could influence their aspirations as well as allowing them to gain the requisite skills and knowledge required to work and study in this area.

Many 3Dcamp students are now undertaking apprenticeships within the VFX industry and a number of the 3Dcamp student alumni are now working within the VFX industry, other tech related industries, or are studying at university on related courses.

3Dcamp aims to be an all year network supported through online social media platforms, where students ask technical questions and post their work. Whilst there is clearly still work to do there have been some successes with students making their own films and improving films made at previous summer camps, see figure 4.1 below.

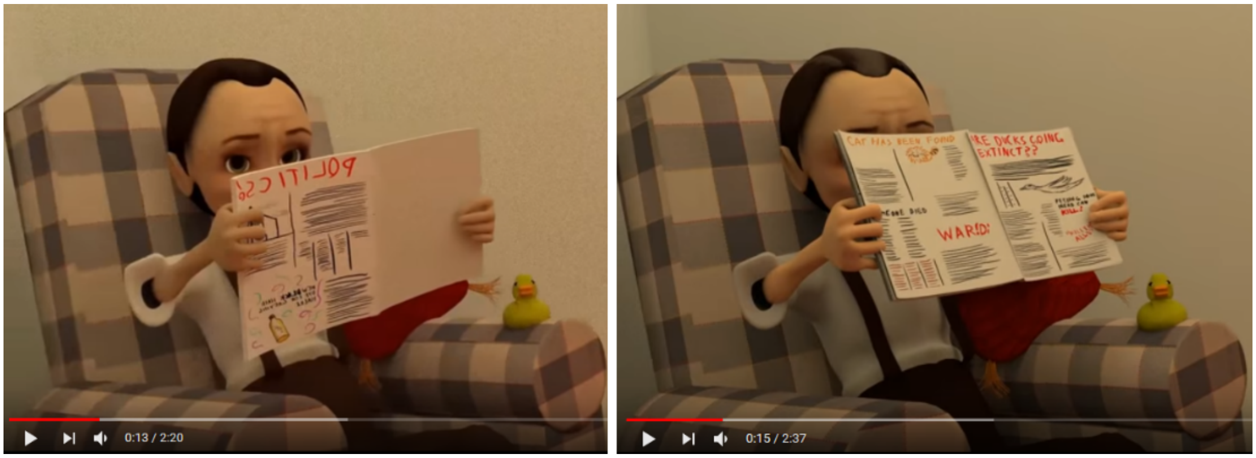

Figure 4.1: Images showing two versions of the same film, the second has been edited by a student independent of the event. Note the correct positioning of text on the magazine and additional greying hair for the character.

Having described the functioning of 3Dcamp, I now argue how computational thinking concepts can be seen in 3D animation.

4.5 Mapping 3D digital animation to computational thinking

Taking the definition of computational thinking (as argued above in *Computational thinking*) to mean:

- the ability to think in abstractions,
- the ability to think in terms of decomposition,
- the ability to think algorithmically,
- the ability to think in generalizations
- the ability to think in terms of evaluations and bringing this about through the creation of an
- automation

The 3Dcamp summer school process will now be mapped on to these concepts:

4.5.1 Abstractions

Abstraction is key to making 3D digital animations, both technically and artistically. Firstly we have a layer of visual abstraction, where an object is represented in a deliberately unrealistic style, with students recognising the features critical to the representation of an object. For example a character might be made without nostrils, as these are considered unimportant to represent the character. This is also linked to computational issues around computational space and computational time. For example, a 3D model might take up a lot of computer memory and/or it might take a lot of computing time to render. Trade-offs need to be made in the complexity of models, balancing the overall ability for the viewer to understand what is being represented, against the space a model will take up and how much time a model will take to render. For example, adding realistic hair to a character's head would increase the space it takes in memory and the time it takes to render the character. The student might decide to colour parts of the character's head instead. Students might also choose to reduce the detail of poorly observed objects, e.g. those in the background or those out of focus; this might involve only modelling part of a scene or making a 'low poly' representation of an object that doesn't feature prominently in a scene, that is an object made up of a limited number of surfaces. This can be seen in figure 4.2.

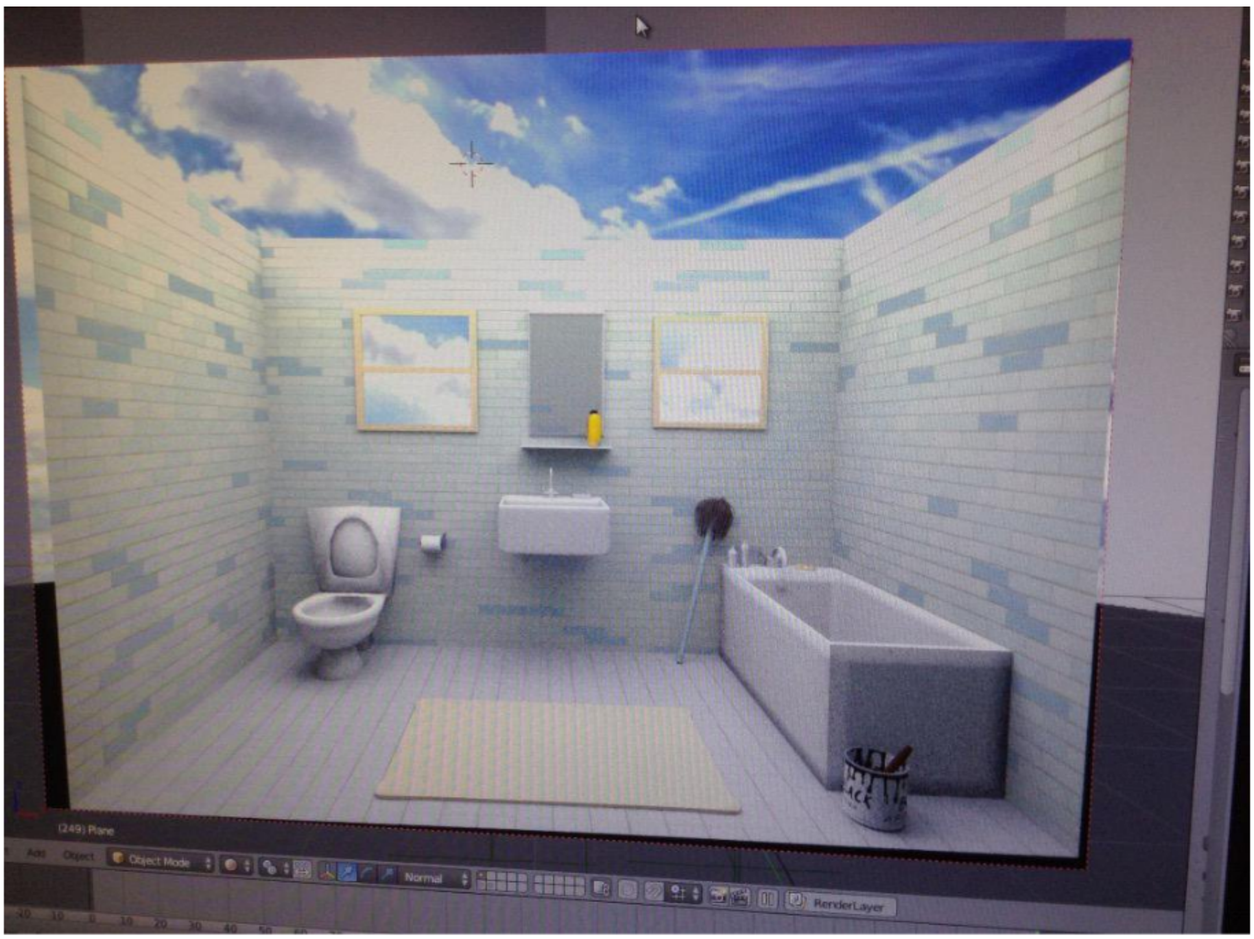

Figure 4.2: note the example of technical abstraction where the rest of the house hasn't been modelled and one of the bathroom ceiling is missing, neither of these are needed as the shot will never show them, this also allows for quicker set creation and render times. Artistic abstraction is apparent, for example where you see the toilet, there has been no attempt to incorporate a flush handle, this reduces computational time and space issues as well as maintaining a simplified artist style.

In terms of procedural abstraction there are several examples where this can be used. Materials used on props might involve complex combinations of nodes, these nodes can be 'packed' into a node group, and people using this node group don't need to delve into the detail to use it. Students might write short pieces of code, or use animation nodes[32] to automate processes, then only reveal the command to execute the automation to other users. See figure 4.3 below for an example of node groups being used to hide the detail of how a texture was made. When making character rigs, a bone might be attached to a limb and restraints put on the movement of this bone to stop it bending in unrealistic ways, or a bone attached to another bone. In both instances the complexity of how this was achieved it hidden from the end user, who just moves the bone, as an interface to the work underneath it.

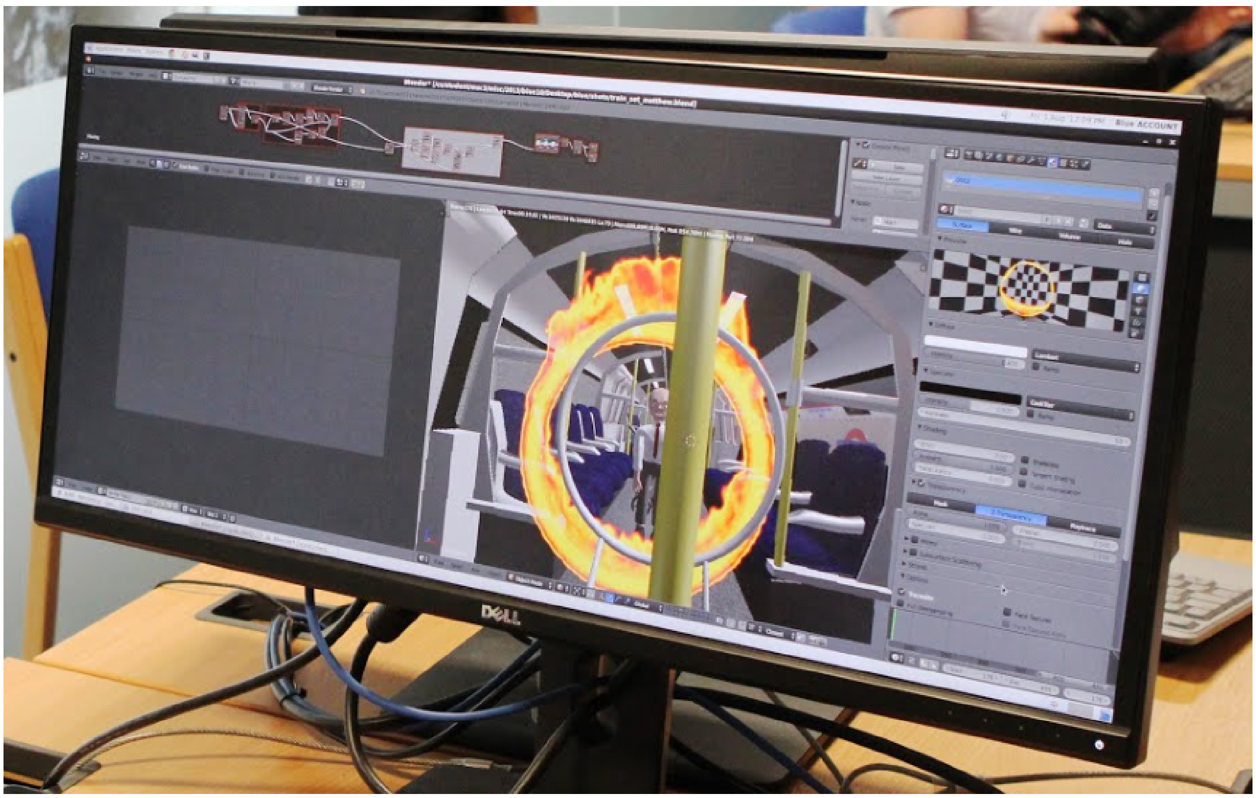

Figure 4.3: node editor being used (at top left of screen) to make fire simulation fit in with the visual style of "No pain no train". Note the grey and black boxes around the nodes, these are node groups.

4.5.2 Decomposition

Burn (2013) notes the use of decomposition when breaking down the tasks and artefacts involved in making a film. I also find this process happening in the creation of 3D films. One of the first tasks undertaken by the students is to build a story, once the ideation phase is complete students then undertake the creation of

[32] a drag and drop programming system https://animation-nodes-manual.readthedocs.io/en/latest/

a storyboard, breaking down the whole film into hand drawn sketches of individual shots. Figure 4.4 shows students creating a storyboard. Each of these shots can then be completed by different students.

Figure 4.4: storyboard development

Once the storyboard is complete, further decomposition occurs and an asset list is created from the contents of each storyboard shot, listing items such as models, animations, sets, lighting, sound etc that are needed to complete the shot. This asset list is imported into the asset management system and each asset can be assigned to a student to create. For an example of this, see figure 4.5. Implementing the idea of the "separation of concerns"(Dijkstra, 1982), assets are created independently from each other using different files.

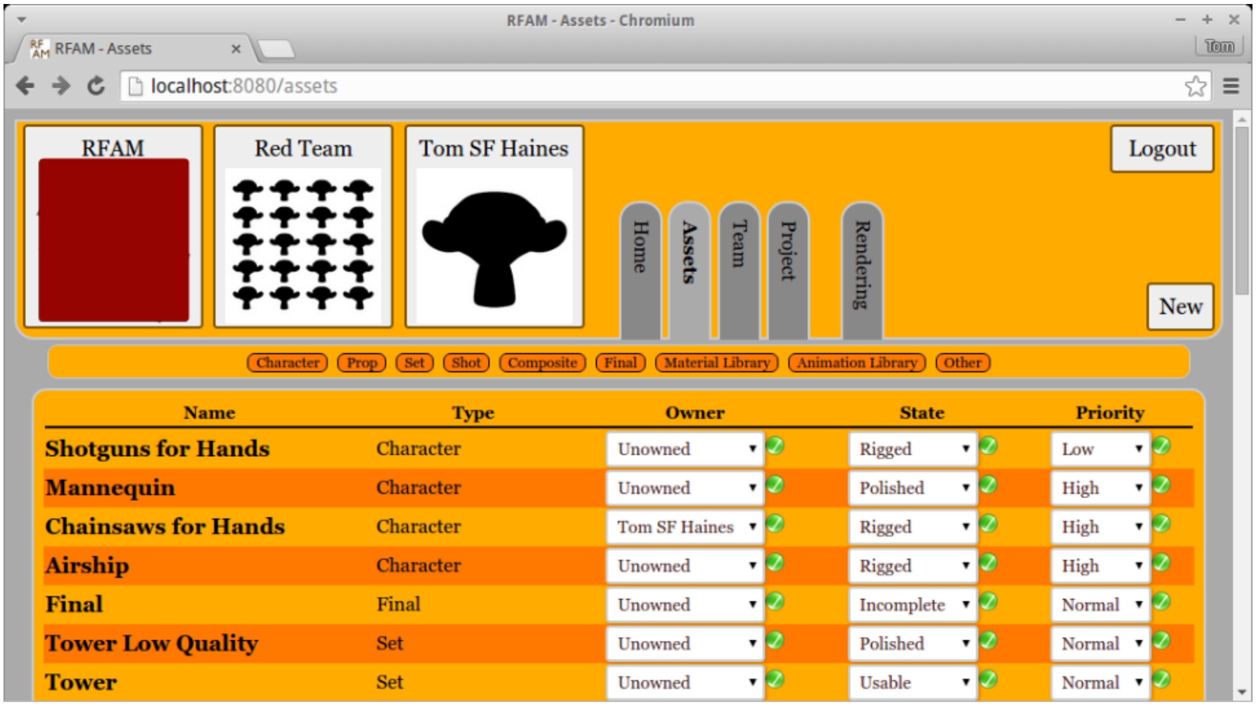

Figure 4.5: the asset management system allows for individual assets such as characters, sets and props to be assigned to different people

When sets and shots are being worked on, they are constructed by 'linking' the assets together. For example, a garden shot would be a single file where a snail character, grass, a fence, a flower bed, a gardener and a patio are all linked in. Each of these assets might have been created by a different person. Very often a shot will be worked on where some of the linked assets are incomplete (see figure 4.6), in this case placeholders or models in development might be incorporated. Students are encouraged to iterate their asset, they might start off with some simple blocks, refine the model, and finally add textures. At each stage of its development the asset can be used in a set or scene. The person working on the shot doesn't need to worry about updating the incomplete characters as that is someone else's job, the nature of linking them into the shot means that the latest versions will be imported into the final shot automatically, when they are updated.

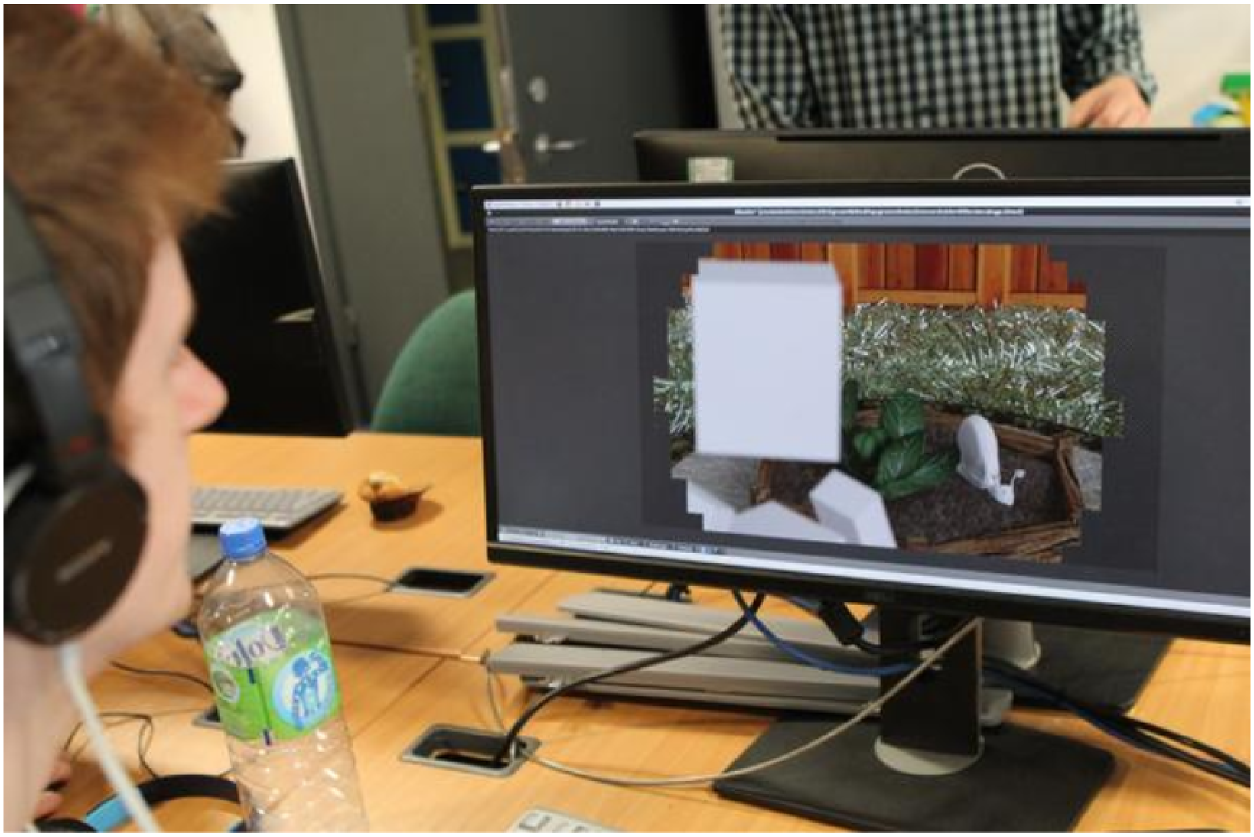

Figure 4.6: student working on a shot where two of the assets, the snail and man characters, have been linked in, but are incomplete. The snail hasn't been textured and the man is in a very early stage of development, being made of untextured cubes.

Further decomposition can occur when students create models, breaking them down into materials, textures, bones, faces, vertices etc. Additionally, some students might break down animations by first blocking them out, then adding extremes and finally polishing.

4.5.3 Generalisation

When building an asset list from the storyboard, students note where certain assets can be reused wholesale or where a model in one shot bears a close resemblance to a model in another shot. An obvious generalisation is the same character or prop appearing across multiple shots, see figure 4.7. This means that only one version of this asset needs to be created and it can be reused multiple times by linking the same asset into different shots.

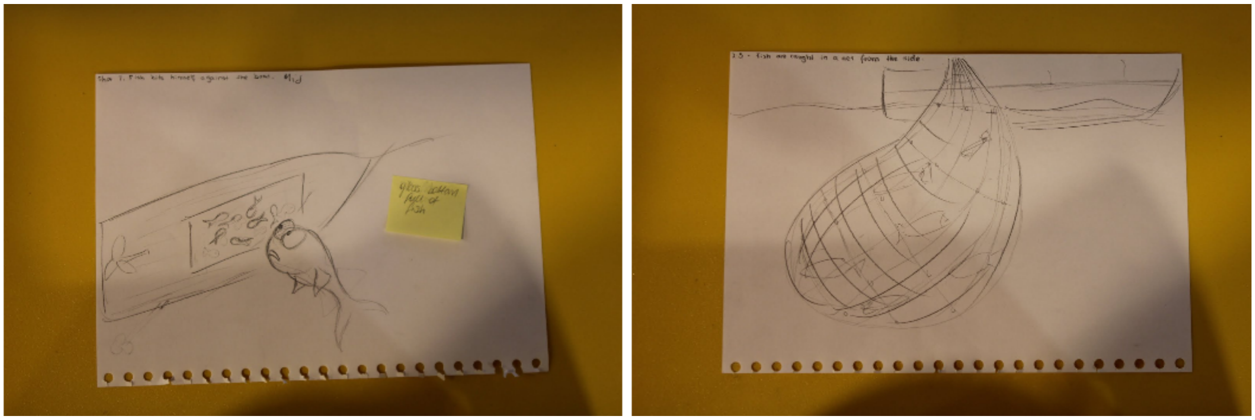

Figure 4.7: two storyboard shots from *Fish and Ships*. The boat and fish inside the boat in the left hand shot were the same boat and fish used in the right hand shot.

Often where several desired assets share common attributes, an abstract/base model is built, for example a base character with a shared animation rig, as seen in figure 4.8. This base model is then saved multiple times and can be used by different students to build their own version of an asset.

Figure 4.8: two characters from *Baby Rumble*. There were four babies in total and all of them shared the same base model and rig, changing the hair style and romper suit colour to create four distinct characters

Students are tasked with recognising the patterns inherent to creating realistic animations, they often have to act out and record their own movements mimicking the desired animation, so that they can emulate this on using the computer program. Walk cycles involve the creation of a pattern of movement that can be looped seamlessly to give the effect of a character moving across the screen. Due to the modular nature of development, each asset is created in a separate file and can easily be incorporated into future productions.

4.5.4 Algorithms

While the creation of computer code is certainly possible in Blender, through the creation of plugins and scripts to automate tasks, 3Dcamp does not promote the creation of algorithms that can build computer code. As noted earlier, algorithms are the end result of the computational thinking thought process, they are a representation of the solution. In 3D digital animation this includes the development of a story, through to the creation of assets, the shots and finally the film being put together in a video editor, see figure 4.9.

Figure 4.9: video editor showing the sound (green) and film (purple) clips used to construct *Fish and Ships*

Within the filmmaking process there are several other examples of the development of algorithms. When creating animations the order and timing of the movement of assets through keyframing is essential. Keyframing can be seen in figure 4.10. Some animations include the use of loops to simulate repeated actions.

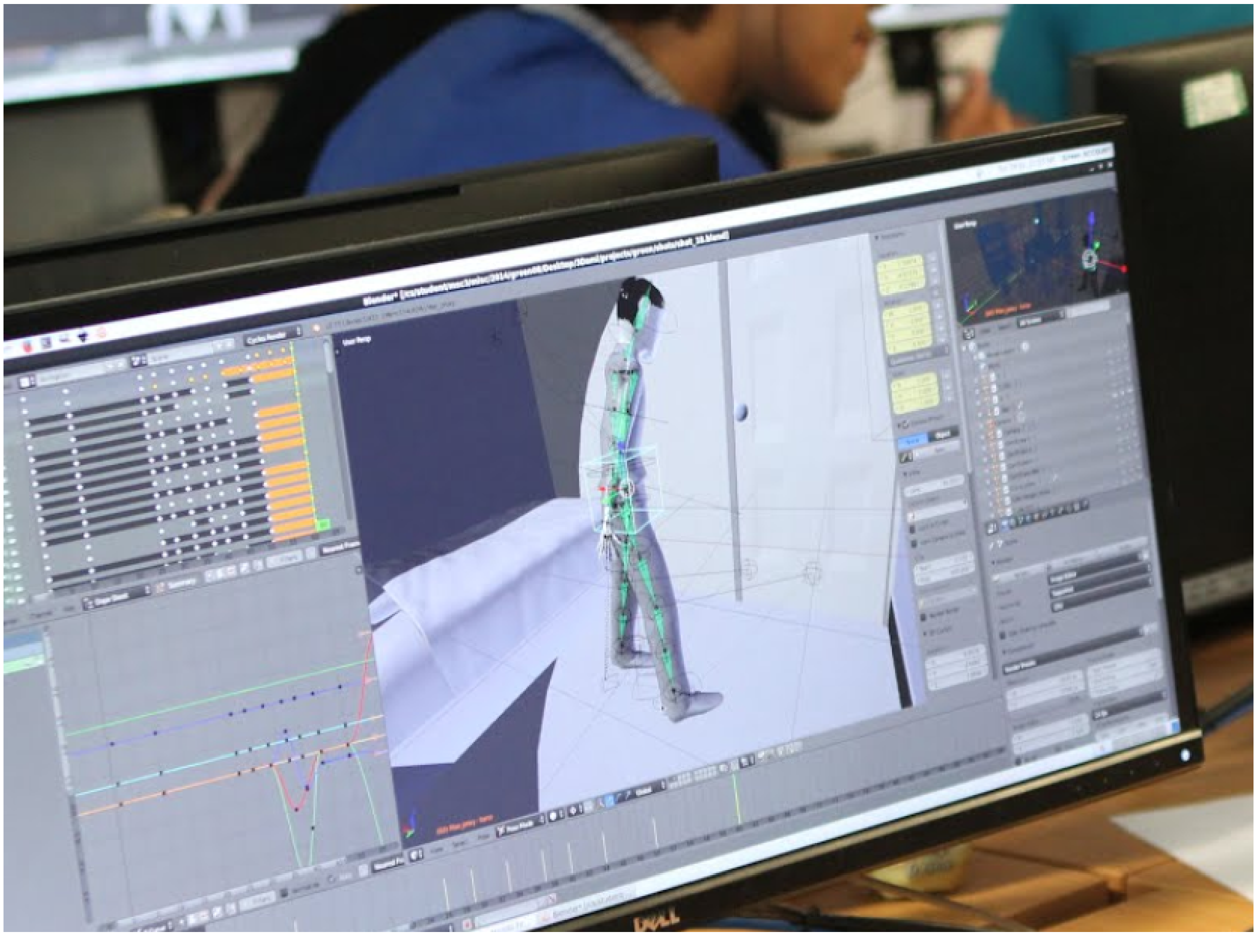

Figure 4.10: keyframing being used to construct character movement. Note that the character is made up of multiple ‘bones’ (in turquoise), each bone can be individually manipulated

Techniques for making specific effects involve the use of physics simulations, where multiple variables need to be adjusted to create the correct effect. Additionally the compositor is a visual programming language allowing you to combine multiple image inputs into a final output, as seen in figure 4.11. For example, if you were trying to add a spaceship to an image of a city you would have to make sure that the lighting on the spaceship matches the lighting of the city, and once both match, you would combine the images into one output. When creating materials and textures to add to a prop or character, nodes are used. These nodes function as a linear programming environment, with data flowing from left to right between nodes, each node performing an action on the data. For example, a node might combine two images and output the merged image, or remove all the red from an image.

Figure 4.11: node editor being used to adjust lighting.

4.5.5 Automation

The process of 3D digital animation allows animations to be automatically created without going through the process of stop motion, frame-by-frame animation. Once the computational thinking steps mentioned above have been completed then the student should have created a computer file of their animation, this is the equivalent of an algorithm to create their film, if they “render” that file the output film clips that can then be brought together to make a complete film. Tools such as physics simulations can be used to automate the process of animation further, particularly where you have multiple moving objects or objects moving in complex ways, such as simulation wind blowing hair or a crowd of sheep trying to get on a train (see figure 4.12). Physics sims can automate the process of creating complex animations, achieving the same effect but saving the student time.

Figure 4.12: a crowd of sheep from *No pain no train*. This demonstrates the use of abstraction and generalisation in a simple sheep model, the sheep has a face, ears, head and body, but no tail or legs. This base model was then used to create four different types of sheep: white small, white large, gold and black. These sheep were then loaded into a physics simulation to automate the animation of them colliding with each other in an attempt to enter the train doors.

4.5.6 Evaluations

Every second of a film involves the creation of 24 separate images or frames, if each frame takes four hours to create on one computer, this means you could spend four days making one second of film. A render farm allows you to use multiple computers when creating/rendering images. For our example of the four hours per frame shot, you could get 24 machines working on all 24 different frames at the same time, resulting in the creation of one second of film in four hours. However, four hours might still be too long a time to wait. Students have to be aware of the computational efficiency of what they are making. 3D digital animation is very much limited by the computing power of the machines available and students need to think of this. The time taken to render a range of individual shots is shown in figure 4.13. As mentioned in the Abstraction section earlier, this might include making a model using a limited number of faces for something that is far away from the camera. It might also involve deciding against using physics simulations such as one to represent hair, glass or water and think of alternative ways to represent artistic features. If they are using simulations, they might be able to adjust the configuration to reduce render time. This all involves experimentation, testing and iteration of solutions to find the optimal setup. One of the big questions that students ask themselves is whether to use ray-tracing or an internal rendering engine. This is the software used to make the final film shots. Ray-tracing simulates paths of light for thousands, millions or billions of light rays, making ultra-realistic effects. This is what the industry mainly uses but can be very slow on even the fastest machines. Internal rendering engines are generally faster but the results often compare badly to ray-tracing.

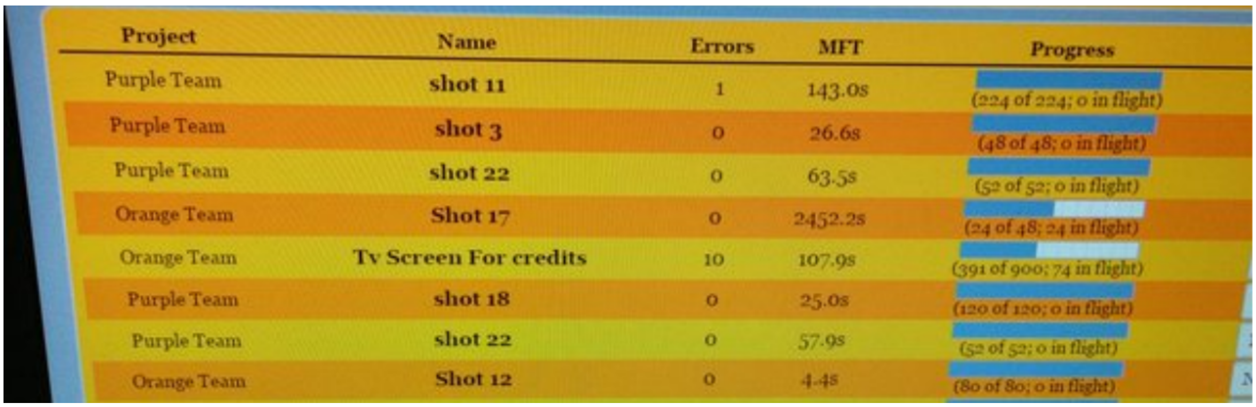

Figure 4.13: image of the render farm running. Note that Orange Team shot 17 is taking nearly 41 minutes per frame, by contrast, Purple Team's slowest shot is shot 11 at 2.4 minutes per frame. This is largely due to the Orange Team using ray-tracing rendering and the Purple Team using the internal rendering engine.

At the start of the seven days, the students are encouraged to make an animatic of their whole story. All the sketches from the storyboard are photographed and imported into a video editor file as individual shots, each shot is then given the correct duration and an animatic video output. From day one they can see their entire film from beginning to end, albeit in a pencil sketch format. Throughout the week as each shot is completed in 3D digital animation, the drawn image is replaced with a film clip and slowly the whole film takes shape. Having the animatic from day one allows the students to see their target outcome and evaluate how close they get to it. There has been one occasion where the at the end of the seven days a film was produced that still contained sketches from the original storyboard, as the team had failed to produce all the animated shots in time, and not met all of their original goals.

4.6 Summary

This chapter outlines a creative curriculum formed by the interaction of creative content, pedagogy and assessment. It describes 3Dcamp, a seven day summer school for young 3D animators, and links the camp to the creative curriculum model. Finally, it maps 3D animation to computational thinking, the first time

3D animation has been mapped in such depth.

Linking with the *domain* component of the systems model of creativity of Csikszentmihalyi (2013), I argue that a creative curriculum needs to have subject skills and knowledge at the core. For 3D animation, this can be loosely defined as the knowledge domains present in computing and media studies, that is computational thinking (e.g. Wing, 2008) and multimodality (Kress & Van Leeuwen, 2001). Whilst the domains of knowledge are important for the creation of 3D films, I argue that in team based education projects, not all parts of the domain are necessary for all students, e.g. it might be the case that a students might spend their whole time modelling characters and never spend any time on lighting or timing of shots. Creative pedagogies involve ambitious projects, simulations of professional environments and involvement of student choice (e.g. Thomson et al., 2012). I connect media and computing literature by describing the similarities of computing's constructionism (Papert & Harel, 1991) to media's audience (e.g. Buckingham, 2003). Finally, for this section, I outline creative assessment models, linking audience and peer validation with Csikszentmihalyi's (2013) concept of *field*.

Next, I describe how 3Dcamp delivers a creative curriculum outlined above by describing the functioning of the camp. I argue that the camp delivers *powerful* knowledge (Young, 2007) as the knowledge is important (as argued above) and students cannot gain it easily elsewhere. 3Dcamp does not involve explicit assessment criteria, the reasoning for this is to support collegiality and to allow student freedom in setting their own targets.

Finally, I undertake the first in depth mapping of 3D animation to computational thinking. I show that each of the standard computational thinking concepts, abstraction, decomposition, algorithms, generalizations, evaluation and automation (e.g. Selby & Woollard, 2013), can be seen in 3D animation. In sum, I argue that computational thinking can clearly expressed through 3D animation, with automation being a key component, with many examples of automation lacking the traditional programming concept seen in most expositions of computational thinking. How computational thinking links to student creation of 3D animations and the centrality of automation not necessarily linked to programming is further explored in *Study 2* below.

5 Objective and research questions

The overall objective of this thesis is to understand the role of 3D animation in supporting the development of digital creativity. To do this I use the systems model of creativity of Csikszentmihalyi (2013) where I explore his concepts of the *domain* and *field*, linking these to research on young digital creators. I look at the range of skills involved in the domain of 3D animation by focusing on computing and media studies, which I argue are the two main subject areas that, combined, define 3D animation. Within school educational settings I look at the GCSE qualifications in computer science and media studies. Amongst young 3D animators I look at student use of *computational thinking*, and *multimodality*, skills and knowledge frameworks involved in defining the *domains* of computing and media studies. The *field* attribute is explored by looking at the range of courses available to and being taken by students in school, looking at factors such as gender, wealth, ethnicity and schooling to see how they affect educational participation. I also look at other forms of social capital (Bourdieu, 1986) possessed by students. The *person* attribute remains largely unexplored by this research, with only a small section on what students themselves consider to be creativity. I consider that *personal* attributes should be the focus of further research, but this lies beyond this thesis.

In summary, I explore three research questions:

1. What characterises the opportunities for learning 3D animation in the formal curriculum?
2. What are the affordances of 3D digital animation work for young people?
3. What possible connections are there between computational thinking and multimodality in the production of 3D digital animation?

To answer these questions I undertook two research studies. Study one looks at national datasets for participation and achievement in school computing and media courses. This allows me to paint a broader picture of access, participation and achievement for digitally creative students in formal school education. These results help describe the background to the individual interviews conducted in study two, as well as informing some of the interview questions. This first study will help answer research question 1.

The second study involved interviewing students engaged with making films on a 3D animation summer camp. Interviews explore the personal attributes of students on the camp, their social and educational backgrounds, and their use of domain specific skills and knowledge. Study two helps to answer research questions 2 and 3, and adds a qualitative element to study one, which provides in-depth data to support the earlier findings.

Combined, these two studies will help explain what it is to be a digitally creative youth in England and outline what it is to be digitally creative using 3D digital animation. The following chapters will outline the methodology, results, limitations and conclusions from the two studies. Finally, I will bring together the results of both studies, in answering the questions posed above.

6 Study 1 - A national picture of computing education using the NPD

The focus of study one is to look at the learning pathways for students potentially interested in 3D animation by looking at the formal educational routes available and taken by digitally creative students in England. Sefton-Green (2013) argues that digital creativity incorporates knowledge and skills from a variety of domains. Whilst it can be argued that all subject areas could be included in those needed to be fully digitally creative through 3D animation, e.g. English language for writing scripts, Geography for making realistic terrain etc, I have decided to focus on two specific subject areas. These subject areas are computer science and media studies, in particular the students taking GCSEs in these subjects. The reason for choosing these two subject areas is that, combined, they cover a significant part of the domain behind 3D animation, including computational thinking in computing, and media literacy in media studies. The focus here will mainly be around the offering, uptake and performance of schools and students in these subjects.

The qualification looked at is the General Certificate of Secondary Education (GCSE), an examination generally taken at the age of 16 in English secondary schools. GCSE computer science is not solely about computer programming, but programming makes up a large proportion of the qualification (e.g. OCR, 2012)[33]. It should be noted that within the English school system, computing as a subject incorporates elements of computer science, information technology and digital literacy (Kemp, 2014b). Where the word *computing* is used in this study, it should be taken to mean the subject as a whole, encompassing all three of these elements and qualifications categorised under computing in addition to computer science.

GCSE CS (e.g. OCR, 2012) covers areas such as programming, ethics, hardware, software, data representation, databases and networking. Topics such as programming would be directly tested through written exams and practical programming sessions. In September 2017 the GCSE in Information Communication Technology (ICT) was discontinued (DfE, 2015b), so a focus on CS only is appropriate for the current educational landscape. GCSE Media (e.g. AQA, 2017) covers the language of media, including narrative, codes and conventions, audiences, production processes and the use of digital technology. Media artefacts are studied on this course including magazines, marketing, newspapers, online, and video games. Whilst it is not necessary to study 3D animation, the components of GCSE media studies clearly link to digital creativity through the artefacts being studied and links in with the semiotic process involved in making 3D films.

[33] the assessed non exam based programming component of the GCSE was dropped in 2017, so it is now feasible that a student could sit an exam without writing any code on a computer - https://www.gov.uk/government/consultations/consultation-assessment-arrangements-for-gcse-computer-science

6.1 The NPD and national datasets

The English government's Department for Education (DfE) records demographic data for all students attending school (both state run and private) between the ages of 3 and 18 (DfE, 2015c), along with individual students' exam results. This system is known as the *national pupil database* (NPD). Demographic data stored about students includes: gender, age, home location, ethnicity, parental wealth and school attended. Exam data includes exam board, course taken, date taken and grade. Combining the demographic data with exam results and descriptive data on schools from Edubase (DfE, 2016a), such as the gender characteristic of a school, we can look at factors that correlate with participation and performance.

Additionally, datasets are publicly available that outline student entries for CS and media using the *compare school performance* government service (DfE, 2019a). These datasets include schools entering students into these subjects for 2015-18, cohort sizes, school demographics and number of hours of media and computing taught. Note here that the number of hours of computing encompasses digital subjects beyond computer science. Whilst these dataset are in the public domain, no systematic study has ever been conducted into media studies uptake by school types (e.g. selective, comprehensive, special; girls, mixed and boys only), English regions, nor have there been studies for number of hours taught. Whilst some analysis has been produced for computer science these figures are not currently up to date (e.g. see Kemp et al., 2016, 2018) and reports do not include number of hours, subjects dropped, student performance, and predictors for students taking computer science courses.

This study will conduct secondary data analysis of the NPD with descriptive analysis for students sitting GCSE exams in 2016. Whilst 2017 and 2018 data does exist, the grading system for the GCSE changed for mathematics and English, meaning that a direct comparison between subjects using that dataset would become less accurate. For example, how do you compare a C grade with a grade 5? In 2016, all subjects were graded between A* and U.

The *compare school performance* government service provides datasets going back to 2012. The focus of this study will mainly be on the four years covering 2015-18 as this is the period after computing was introduced (2014) and the datasets are consistent in the data they hold.

The combination of both the NPD and *compare school performance* datasets allows for a broad analysis of this topic. *Compare school performance* allows for: the description of schools offering the subjects, summaries of regional provision, student uptake within schools and regions, number of hours taught each week, descriptions of school turnover when offering these courses. The NPD allows for: descriptive and predictive models of subject uptake by student demographics including gender, ethnicity, poverty indicators; as well as student achievement overall and by gender.

No research on this scale has yet been conducted into the formal learning pathways of digital makers in English schools. This study will allow me to look at the demographic backgrounds of students sitting exams that map on to digital learning pathways. It will also allow me to argue more widely how STEAM might affect female uptake of digitally creative courses. This study should help answer the research question: *What characterises the opportunities for learning 3D animation in the formal curriculum?*. This study of the NPD will raise several questions that can be further explored during the summer animation camp.

6.2 Participants

This research looks at all GCSE results for the 2016 English student cohort using the NPD. This cohort numbers 476,559 students and includes *all* students sitting GCSE exams in that year, with 60,736 (male=48,348; female=12,388) students taking the GCSE in computer science and 42,115 (male=21,872; female=20,243) taking the GCSE in media studies.

The dataset from the *compare school performance* database stores student entry data for *all* students sitting exams, including GCSEs, at age 15-16: in 2015 (595,827), 2016 (583,798), 2017 (569,710) and 2018 (565,686).

Where numbers of students differ in the data below, this is because explanatory variables are missing, and students with missing variables have been excluded.

6.3 Ethics

This research was approved by the University of Roehampton's Ethics committee (EDU 15/ 091) in June 2016. Ethics approval was needed for study one because the national pupil database stores personal data about individual students. This data includes their gender, ethnicity, whether they have English as an additional language, whether they have been categorised as having special educational needs, and it also stores poverty indicators in the form of IDACI and Pupil Premium (discussed below). Students are linked to schools and their exam results through a unique reference number. The process of gaining access to this dataset involves completing an application to the English Department for Education (DfE) stating the purpose of the research and why this data is necessary to complete that purpose. This was completed in June 2016 and access to the data approved in September 2016.

Data was processed at the University of Roehampton in a secure environment made up of a non-networked and encrypted computer. Before any data was published, including this PhD, it had to be sent to the DfE data team for approval. The physical security of the data was taken into consideration by the DfE when they approved the research bid.

Where results from the national pupil database were highlighting five or fewer students, this data was anonymised, by rounding to the nearest five. This anonymisation technique is in line with DfE recommendations.

NPD was kept until July 2019, when the contract to use the dataset expired. Disk drives containing the data were then overwritten several times and physically destroyed.

No formal ethics approval process was undertaken for the use of the *compare school performance* database as this data is in the public domain. Additionally this dataset does not contain any student personally identifiable data and as it is already anonymised by the DfE.

6.4 Data analysis

All data analysis was undertaken in the R programming language (Field, Miles, & Field, 2012).

Within the NPD the following fields were used:

Students were classified as being either female or male (coded 0 and 1 in the regression models used). No other descriptions of gender are stored in the NPD.

Students are recorded as eligible for *free school meals* if they are in some form of care or their parents have a limited income. Students who have qualified for free school meals at any point within the previous 6 years are categorised as *pupil premium* and schools will receive extra funding to support these students (DfE, 2016b). This categorisation can be used as a rough indicator of social deprivation and a way of categorising students as working class (Baars, Mulcahy, & Bernardes, 2016). However, this measure isn't without its critics, with Hobbs and Vignoles (2010) noting that over half of the poorest students wouldn't be categorised as pupil premium.

An alternative and more finely grained poverty indicator is the income deprivation affecting children index (*IDACI*). Each student has an IDACI score attached to their student record. This continuous value is an indicator of the wealth of the area that a child lives in, with values close to 0 reflecting richer areas and values close to 1 reflecting poorer areas (DCLG, 2015).

The NPD records the ethnicity of students using the categories: Asian (ASIA), Black (BLAC), Chinese (CHIN), mixed (MIXD), White (WHIT), any other ethnic group (AOEG), undeclared and missing (UNCL). Each of these groupings can be further broken down, for example Asian can be broken down into Bangladeshi, Indian, Pakistani and Asian other. Note that Asian here means all students from an Asian heritage excluding those with Chinese ancestry, the Chinese grouping allows for no further breaking down of the category. White students make up the majority of students in English schools, but it has been argued that the results of working class ethnic groupings are significantly different from other groups as to warrant separate analysis, in particular work has been done recently looking at the academic success of white working class boys (Baars et al., 2016). To define working class students I will be using the ethnic category and the pupil premium status of the student. Other ethnic differences such as the performance differences between Bangladeshi and Indian students, will not be explored in this thesis.

English school children sit mathematics and English standardised assessment tasks (or SATs) at the end of primary school. Most students are 11 years old when they sit these exams. These results are stored in the NPD as a grade between 0 and 5, with 5 being the highest grade possible for this age group. SATs are used as predictors of future attainment, with schools held accountable for the progress made by students based on their entry SATs grades. Additionally KS2 results of a subject cohort are used to influence exam grade boundaries (Benton & Sutch, 2014).

The GCSE is the most common way for students to be assessed at the end of secondary school in England. Each exam sat at GCSE was assigned a grade on the A* to U range, with A* being the highest grade. GCSE grades are recorded for every student result in the NPD. For the purposes of this thesis I am converting grades to numbers, this allows us to look at partial grade data, where 0.25 would be the equivalent of a quarter of a grade, thus allowing us to quantitatively compare grades and build statistical models[34].

Table 6.1: GCSE grades and our numeric equivalent

Grade	A*	A	B	C	D	E	F	G	U
Point equivalent	8	7	6	5	4	3	2	1	0

Girls on average outperform boys at GCSE exams and student academic ability needs to be controlled for when looking for differences in attainment for GCSE computer science and media studies. Whilst the SATs grades provide background information about the mathematics and English performance of students, this result is generally 5 years before the GCSE exam and the ability of students might have changed significantly since then. Lacking the means to administer my own tests to tens of thousands of students involved in this research, I have adapted Stoet and Geary's (2018) model of looking for differentials between subjects, in our case GCSE examination results. This allows me to control for academic ability by looking at the difference

[34]There were changes in 2017 to grade some subjects on a 9 point system, the grades used in this thesis are not comparable with the new grading system http://gov.uk/government/publications/gcse-new-grading-scale-factsheets

between the average grade in a given subject, GCSE computer science and media studies, and the average grade in other subjects.

For example, a student taking computer science and three other subjects where they get A (7), B (6) and C (5), would have an 'ability' of 6, the average. If they scored a C (5) grade in computer science, they will be doing worse in computer science by 1 grade (i.e. 6-5).

As well as offering mixed gender provision, schools in England can be exclusively for male or female students. The school gender characteristic for every school is stored in the Edubase database (DfE, 2016a) and student records from the NPD can be linked to this information using the school's Unique Reference Number (URN).

Within the *compare school performance* database the following fields were used:

The data provided is split into years; this allows for the analysis of trends in the data.

Each subject is allocated a qualification level, discount code and description. The qualification level stores details on whether the qualification is a GCSE, or other qualification. The discount code is a DfE defined value that is used to group separate qualifications under one umbrella grouping. For example, "CK1" lists all the computing qualifications, "KA2" lists all the media and film qualifications. The description is the name of the course, for example "computer science". Using a combination of these fields I was able to analyse only the GCSE results, and filter down to individual entries for GCSE computer science and GCSE media studies.

Entries are attached to individual schools, which are identified by their unique reference number (URN). This URN allows for linking to school demographic data on pupil premium, location and school gender. It also allows matching of schools between years. In the case below (Tables 15 & 16) the change in schools offering CS and media was recorded by looking at the schools that existed in 2017 *and* 2018, calculating the number of schools that dropped or took up the courses. This filters out any schools that closed between those years, or opened for the first time in 2018.

Total student entries are recorded against schools and subjects taken by schools. This allows for subject entry cohorts to be compared against overall school populations. It also allows me to combine school and subject cohort populations to summarise provision by region and school type.

There are several different school types reported by the *compare school performance* database. Schools can be classified as independent (private paying institutions) or state schools. Both state and independent schools can be classified as special schools (for students with special needs). Within state schools there are grammar schools (with entry exams) and comprehensive schools (for those without entry exams). Comprehensive schools combine a variety of minor school types including secondary moderns and technical schools. For the purpose of this research I have decided to look at all comprehensive schools combined.

The entry into schools can be restricted to individual genders. Schools can be either female only, male only, or mixed (also known as co-educational).

Each school comes with a variety of location information, including postcode, local authority and region. For the purpose of this research I am looking at regional provision only.

The percentage of pupil premium students in a school is recorded and used here to indicate the poverty level of students within that school. As noted above this can only be considered a rough indicator.

The number of hours taught for each subject is split between key stages. Where KS3 covers the first part of secondary school, with students aged 11 to 14; KS4 covers the secondary part of secondary schools, with students aged 14 to 16; KS5 covers college level, where students are aged 16 to 18. GCSE exams are generally taken at the end of KS4, when students are 15 or 16 years old. The figure for the number of hours is calculated by sampling teaching on a given day in early November each year, this involves between 75% and 79% of schools (DfE, 2019b). Figures here are for *computing* and *media*, which mean that the hours taught might not be directly related to the GCSE in these subjects, but might be supporting other courses or be more generalist. This subject category taught is allocated by the schools themselves, with only guidance from DfE.

6.4.1 Use of descriptive statistics

Descriptive statistics are used to show the:

1. uptake of GCSE CS and media studies in England between 2015 and 2018. Statistics used include the number of providers offering the subject, the number of students taking it, the number of students who attend institutions where the courses are offered and could therefore potentially sit those courses. And these statistics are described as percentages. (Tables 6.2 & 6.3);
2. uptake of GCSE CS and media studies in by school type between 2015 and 2018. Statistics used include the number of providers in each school type who offer the course, the number of students and students taking the course, the number of students who attend institutions where the courses are offered and could therefore potentially sit those courses. And these statistics are described as percentages. (Tables 6.4 & 6.5). The same statistics are used in Tables 6.6 & 6.7, where the data is further broken down by the gender intake of the schools;
3. uptake of computing by the pupil premium poverty indicator. The total number of schools in England

is broken into deciles, being split on the percentage of pupil premium students within each school cohort. Schools categorised as 1, are schools that are serving the richest communities, those under 10 are serving the poorest communities (figures 6.1 & 6.2);

4. uptake of GCSE CS and media studies by the region where schools are situated, these figures are for 2018. Statistics used include the number of providers in each region who offer the course, the number of students and students taking the courses, the number of students who attend institutions where the courses are offered and could therefore potentially sit those courses. And these statistics are described as percentages. (Tables 6.8 & 6.9). These figures are shown longitudinally for the years 2015-18 with figures 6.3 & 6.5 showing the percentage of students taking the subjects by regional and figures 6.4 & 6.6 showing the percentage of providers in each region who offer the subject;
5. subject hours of *computing* and *media* each week for the years 2012-18 by keystage (figures 6.7 & 6.8);
6. number of schools that existed in 2017 which are offering the subjects or have dropped the subjects in 2018 (Tables 6.10 & 6.11);
7. relationship between gender and GCSE computer science, GCSE media studies, and other subjects, focusing on: the ethnicity and working class status of students using pupil premium (Table 6.12), the working class status of students using IDACI deciles (figure 6.9), and ethnicity and working class status of students using IDACI quartiles (figure 6.10).

6.4.2 Inferential statistics

Logistic regression using Wald chi-square (Field et al., 2012) is used to analyse the link between gender, ethnicity, wealth (pupil premium) and the uptake of computer science and media, given that the outcome variable is categorical (Tables 6.13, 6.14, 6.15 & 6.16). Statistical models of participation only look at the students potentially able to take a subject, i.e. those students in a school where there was an examination group. In 2016 ~68% of students were in schools that had GCSE CS examination groups (Kemp et al., 2018).

Multivariate analysis using general linear models (Field et al., 2012) are used to look at the impact of gender on attainment when controlling for student academic ability. To control for student ability, attainment in computer science is compared against the average grade in all other GCSEs, as noted above. In particular the research studies the impact of: gender given the 'ability' in other subjects (Table 6.17); and the impact of gender on a subject given their 'ability' in CS or media (Tables 6.18 & 6.19).

The significance of p-values are given throughout as * for p-values < 0.05, ** for p-values < 0.01, *** for p-values < 0.001 (high significance). Additionally, p-values are given by $\Pr(>|z|)$.

Where appropriate, effect-sizes have been reported (mostly as R^2): 0.2 is an indicator for a small effect-size and 0.5 an indicator of a medium effect-size (Coe, 2002). Cohen's d was used in Section 4.2.1 and Cox and Snell R^2 values were used as our measure of the effect size present in the logistic regression (Field et al., 2012).

6.4.3 Assumptions

- Whilst I have not tested the normality of the data, the central limit theorem tells argues that where n>30 I can assume normality for our datasets (Field et al., 2012, p. pp43). In all t-tests used above n>30, allowing me to use the Welch t-test.
- I assume that the letter based grade system used for GCSE can be converted to a numerical scale and a linear relationship can be assumed, i.e. that the difference between an A* and an A is the same as the difference between a D and C, and a U and G.
- I assume that the ability of a student can be gauged from the average of their results in other subjects.
- Results and predictive statistics data used is only for 2016; 2017 and 2018 datasets are available but the grading system used is inconsistent across subjects. Results from following years might be different.
- I assume that the results in CS, Media and other subjects are comparable to each other and that individual exam boards have not inflated or deflated results.
- I assume that exams taken with different exam boards are equivalent and can be combined to form statistics about a GCSE CS population
- I assume that there are no major differences in teacher quality between different school types and schools serving female and male populations.
- The data used for results and predictive models focuses on students attending schools offering the subjects that are being focused on. For example, in 2016 68% of students were in a school where CS was on offer, therefore 32% of students are missing from this analysis.
- The ethnic groups used are broad, and this paper has not looked into more fine grained groups such as Bangladeshi and Pakistani students.
- Where subjects are compared to CS and media, I take a group of the largest subjects (n>30,000), other smaller subjects might have compared differently.

6.5 Results

6.5.1 Subject uptake summary

Between 2015 and 2018 GCSE computer science has seen an increase in numbers of students taking the course (table 6.2, 5.6% to 12.4%), numbers of schools offering the course (31.8% to 61.3%) and the potential numbers of students able to take the course (43.7% to 79.2%). It should be noted that the percentage of possible students who take CS is similar for 2016-18 (15.3%, 15.7% and 15.6%); this suggests that whilst more schools are offering the course, within those schools cohort sizes are steady.

For the same period, GCSE media saw a decline in overall provision (table 6.3). Total number of students taking the course dropped (8.9% to 7.4%), institutions offering the course declined (33.9% to 30.3%) and the reach of the subject dropped (47.0% to 45.1%)

Year	Total students	Total URN	Subject URNs	Possible students	Actual students	% of possible students	URN %	% of all students	reach % of all students
2015	595827	4548	1446	260403	33492	12.9	31.8	5.6	43.7
2016	583798	4602	2355	404206	61938	15.3	51.2	10.6	69.2
2017	569710	4595	2686	438975	68992	15.7	58.5	12.1	77.1
2018	565686	4615	2827	447867	70061	15.6	61.3	12.4	79.2

Table 6.2: Schools offering GCSE CS

Year	Total students	Total URN	Subject URNs	Possible students	Actual students	% of possible students	URN %	% of all students	reach % of all students
2015	595827	4548	1543	280137	52751	18.8	33.9	8.9	47.0
2016	583798	4602	1479	260269	46906	18.0	32.1	8.0	44.6
2017	569710	4595	1529	279554	45501	16.3	33.3	8.0	49.1
2018	565686	4615	1397	254957	41742	16.4	30.3	7.4	45.1

Table 6.3: Schools offering GCSE Media

6.5.2 Subject uptake school type

Amongst provider types, grammar schools are marginally more likely to offer GCSE CS than comprehensives (table 6.4, 81.0% vs 79.7%), however, when you look at the population reach of the schools, only 81.8% of grammar school students were in an institution where CS was offered, compared to 84.0% of comprehensive school students. Students in state special schools were least likely to take CS, with only 1% of all special school students doing so, compared to 2% of independent special schools students and 12.8% of comprehensive and 19.8% of grammar school students.

Media studies provision shows a large difference between comprehensive and grammar schools (table 6.5). With non-selective schools being over four times as likely to offer the GCSE than grammar schools (43.2% vs 9.8%). Over half of comprehensive students were in a school offering the subject, compared to one in five grammar school students.

Type	All schools	All students	Subject schools	School %	Population reach	Reach %	Subject students	Student %
Comprehensive	3012	487950	2400	79.7	409698	84.0	62652	12.8
Grammar	163	23197	132	81.0	18966	81.8	4596	19.8
Ind Special	209	2007	10	4.8	195	9.7	40	2.0
Independent	822	45701	266	32.4	18693	40.9	2703	5.9
Special	409	6831	19	4.6	315	4.6	70	1.0

Table 6.4: GCSE computer science uptake by school type, 2018

Type	All schools	All students	Subject schools	School %	Population reach	Reach %	Subject students	Student %
Comprehensive	3012	487950	1302	43.2	249614	51.2	40685	8.3
Grammar	163	23197	16	9.8	2347	10.1	393	1.7
Ind Special	209	2007	13	6.2	143	7.1	28	1.4
Independent	822	45701	45	5.5	2527	5.5	557	1.2
Special	409	6831	21	5.1	326	4.8	79	1.2

Table 6.5: GCSE media uptake by school type, 2018

Boys schools offered better CS provision than all girls and mixed gender schools across every school type, besides independent schools (table 6.6). The best uptake was amongst all boys grammar schools, where 23.3% of students took the subject, compared to only 15.7% of girls in girls only grammar schools. There were no examples of girls special schools offering the subject.

Students in all boys schools are the most likely to be taking media within comprehensive, grammar and special schools (table 6.7). Comprehensive schools are much more likely to offer media than any other type of school, with similar school percentages (Boys 41.5%, Girls 42.1%, mixed 43.3%) and student reach (Boys 48.8%, Girls 50.3%, mixed 51.3%) for each of the gender groupings

Type	Gender	All schools	All students	Subject schools	School %	Population reach	Reach %	Subject students	Student %
Comprehensive	BOYS	94	13340	82	87.2	12248	91.8	2534	19.0
Comprehensive	GIRLS	145	22630	92	63.4	15250	67.4	1572	6.9
Comprehensive	MIXED	2773	451980	2226	80.3	382200	84.6	58546	13.0
Grammar	BOYS	56	7944	48	85.7	6816	85.8	1853	23.3
Grammar	GIRLS	60	8428	46	76.7	6630	78.7	1323	15.7
Grammar	MIXED	47	6825	38	80.9	5520	80.9	1420	20.8
Ind Special	BOYS	21	205	3	14.3	89	43.4	21	10.2
Ind Special	GIRLS	5	25						
Ind Special	MIXED	183	1777	7	3.8	106	6.0	19	1.1
Independent	BOYS	72	4991	13	18.1	1026	20.6	185	3.7
Independent	GIRLS	169	9145	59	34.9	4249	46.5	611	6.7
Independent	MIXED	581	31565	194	33.4	13418	42.5	1907	6.0
Special	BOYS	42	491	3	7.1	39	7.9	14	2.9
Special	GIRLS	2	40						
Special	MIXED	365	6300	16	4.4	276	4.4	56	0.9

Table 6.6: GCSE computer science uptake by school type and school gender, 2018

Type	Gender	All schools	All students	Subject schools	School %	Population reach	Reach %	Subject students	Student %
Comprehensive	BOYS	94	13340	39	41.5	6515	48.8	1136	8.5
Comprehensive	GIRLS	145	22630	61	42.1	11378	50.3	1761	7.8
Comprehensive	MIXED	2773	451980	1202	43.3	231721	51.3	37788	8.4
Grammar	BOYS	56	7944	8	14.3	1169	14.7	206	2.6
Grammar	GIRLS	60	8428	4	6.7	589	7.0	92	1.1
Grammar	MIXED	47	6825	4	8.5	589	8.6	95	1.4
Ind Special	BOYS	21	205						
Ind Special	GIRLS	5	25						
Ind Special	MIXED	183	1777	13	7.1	143	8.0	28	1.6
Independent	BOYS	72	4991						
Independent	GIRLS	169	9145	3	1.8	172	1.9	26	0.3
Independent	MIXED	581	31565	42	7.2	2355	7.5	531	1.7
Special	BOYS	42	491	3	7.1	41	8.4	12	2.4
Special	GIRLS	2	40						
Special	MIXED	365	6300	18	4.9	285	4.5	67	1.1

Table 6.7: GCSE media uptake by school type and school gender, 2018

6.5.3 Subject uptake by state school area wealth

Schools serving richer areas are more likely to be offering GCSE CS in 2018 than their equivalents serving poorer areas (figure 6.1, 81% of schools in the richest areas vs 69% in the poorest areas). Whilst there is a rough correlation between the wealth of an area and the chance a school offers CS, the schools serving the top 10% of the richest areas are less likely to be offering CS than those serving the next 5 richest areas.

It is harder to see trends in media provision outside the richest area (figure 6.2). Schools serving the top 10% of the richest areas are the least likely to be offering media, almost half as likely as any other grouping.

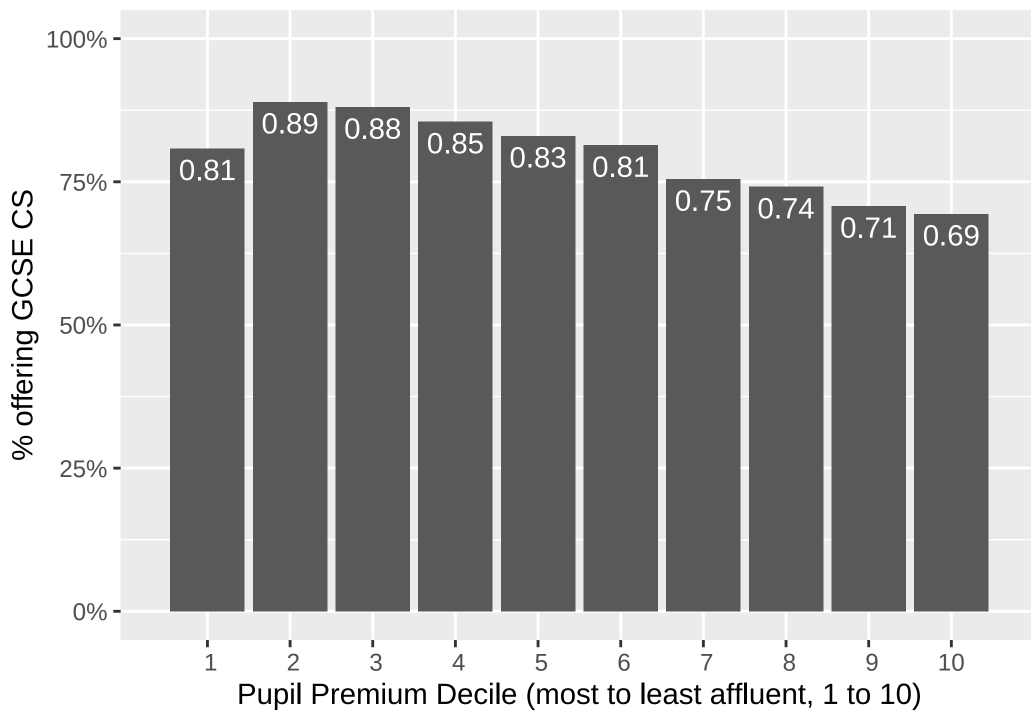

Figure 6.1: Likelihood of state school offering GCSE CS, 2018 (excluding special schools)

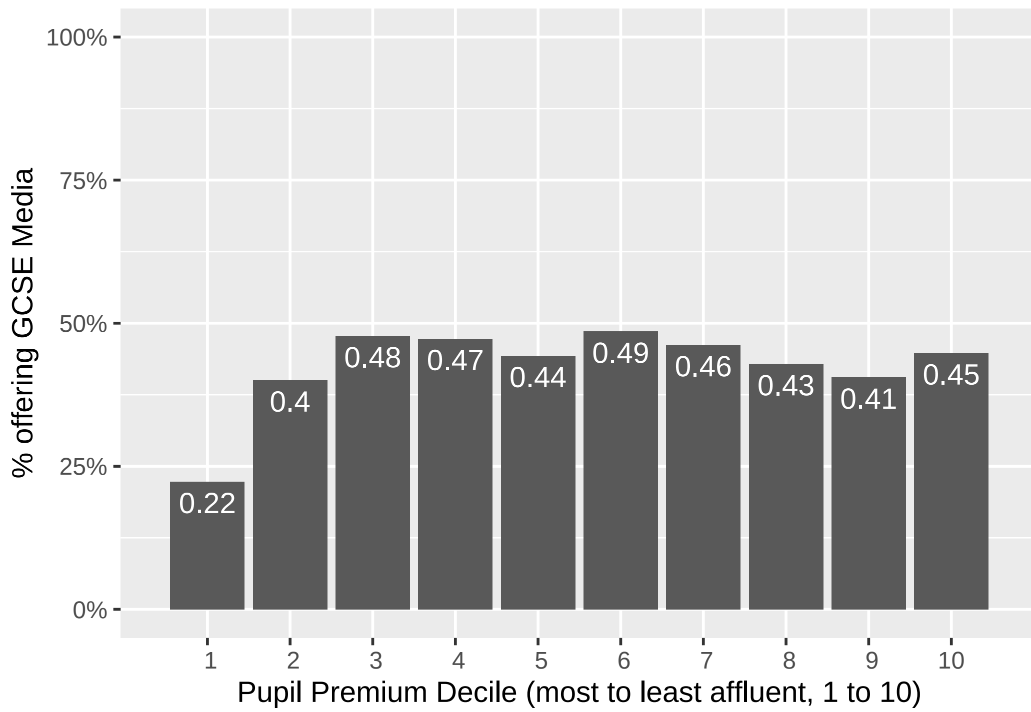

Figure 6.2: Likelihood of state school offering GCSE Media, 2018 (excluding special schools)

6.5.4 Subject uptake by region

London is the least likely region to be offering GCSE CS (table 6.8), with only 57.1% of schools taking the subject compared to the most popular area, the North West, with 64.9%. Within regions, the North West had 13.1% of all students taking the subject, compared to only 10.5% in the North East.

The East of England has nearly 40% of schools offering media studies (table 6.9), compared to only a quarter of schools in the South West. 9.4% of students in London took media, compared to only 5.3% of students in the North East.

Cohort sizes for media studies are generally larger than those for CS.

	Population	Subject reach	Subject actual

Region	Schools	Students	Schools	Students	% of all schools	% of all students	Students	% of all students	% of students in subject schools	Avg Cohort
North West	627	75103	405	62382	64.6	83.1	9873	13.1	15.8	24.4
East of England	498	64314	323	52760	64.9	82.0	8211	12.8	15.6	25.4
South West	458	54755	297	44561	64.8	81.4	6666	12.2	15.0	22.4
West Midlands	546	62810	323	49898	59.2	79.4	7963	12.7	16.0	24.7
North East	209	25569	123	20235	58.9	79.1	2684	10.5	13.3	21.8
East Midlands	378	47889	234	37234	61.9	77.8	6033	12.6	16.2	25.8
South East	781	94877	470	73753	60.2	77.7	12089	12.7	16.4	25.7
Yorkshire and the Humber	418	55671	252	42952	60.3	77.2	5932	10.7	13.8	23.5
London	700	84698	400	64092	57.1	75.7	10610	12.5	16.6	26.5

Table 6.8: GCSE computer science uptake by region, 2018

Region	Population		Subject reach				Subject actual			
	Schools	Students	Schools	Students	% of all schools	% of all students	Students	% of all students	%of students in subject schools	Avg Cohort
East of England	498	64314	192	34498	38.6	53.6	5997	9.3	17.4	31.2
London	700	84698	260	44961	37.1	53.1	7936	9.4	17.7	30.5
East Midlands	378	47889	137	23933	36.2	50.0	3677	7.7	15.4	26.8
South East	781	94877	274	46395	35.1	48.9	8042	8.5	17.3	29.4
Yorkshire and the Humber	418	55671	128	23932	30.6	43.0	3380	6.1	14.1	26.4
North East	209	25569	61	10205	29.2	39.9	1348	5.3	13.2	22.1
West Midlands	546	62810	148	23669	27.1	37.7	3859	6.1	16.3	26.1
North West	627	75103	164	27503	26.2	36.6	4076	5.4	14.8	24.9
South West	458	54755	117	19861	25.5	36.3	3427	6.3	17.3	29.3

Table 6.9: GCSE media uptake by region, 2018

Whilst the percentage of schools offering GCSE CS has been increasing year on year since 2015 across regions (figure 6.3), there was a minor drop between 2017 and 2018 in the North East. Student percentages are less positive (figure 6.4), with minor drops in provision between 2017 and 2018 for the South East, East Midlands, North West and East of England. Students in the South West, Yorkshire and the Humber and North East were less likely to take GCSE CS in 2018 than they were in 2016.

Media studies provision between 2015 and 2018 was down across all regions when looking at the percentage of providers offering the subject (figure 6.5), and the percentage of students taking the subject (figure 6.6).

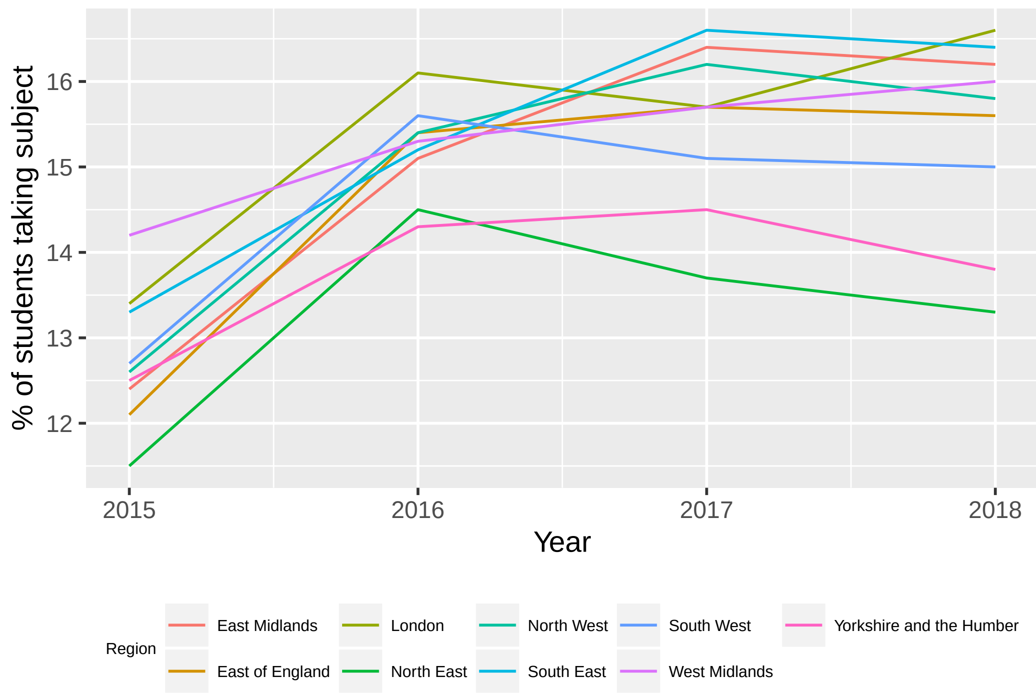

Figure 6.3: GCSE CS regional provision, by % of all students, 2015-18

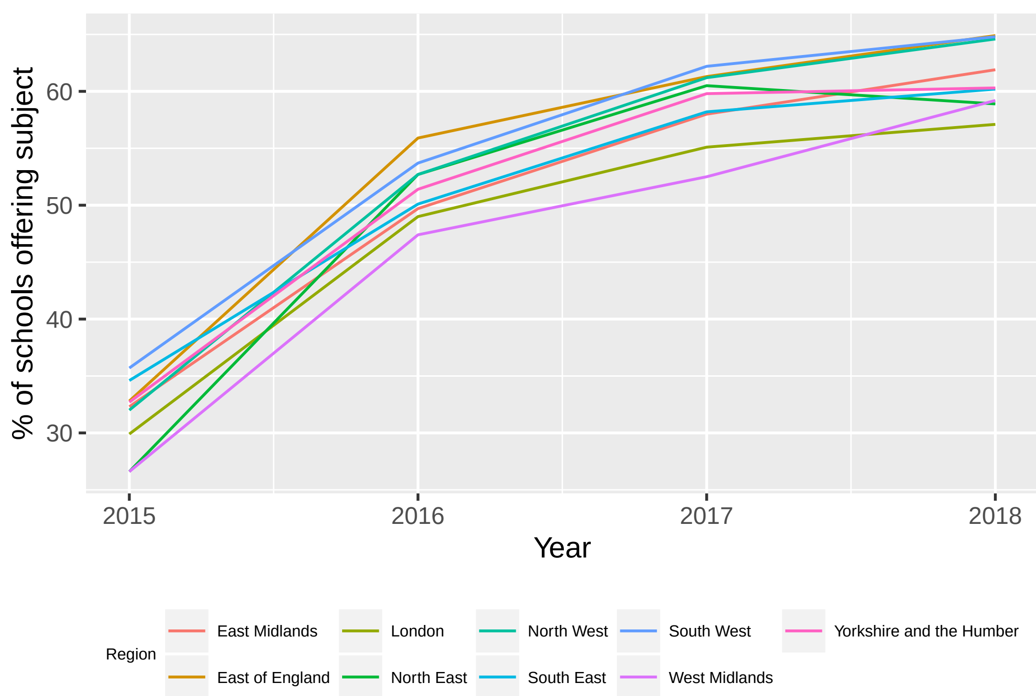

Figure 6.4: GCSE CS regional provision, by % of providers, 2015-18

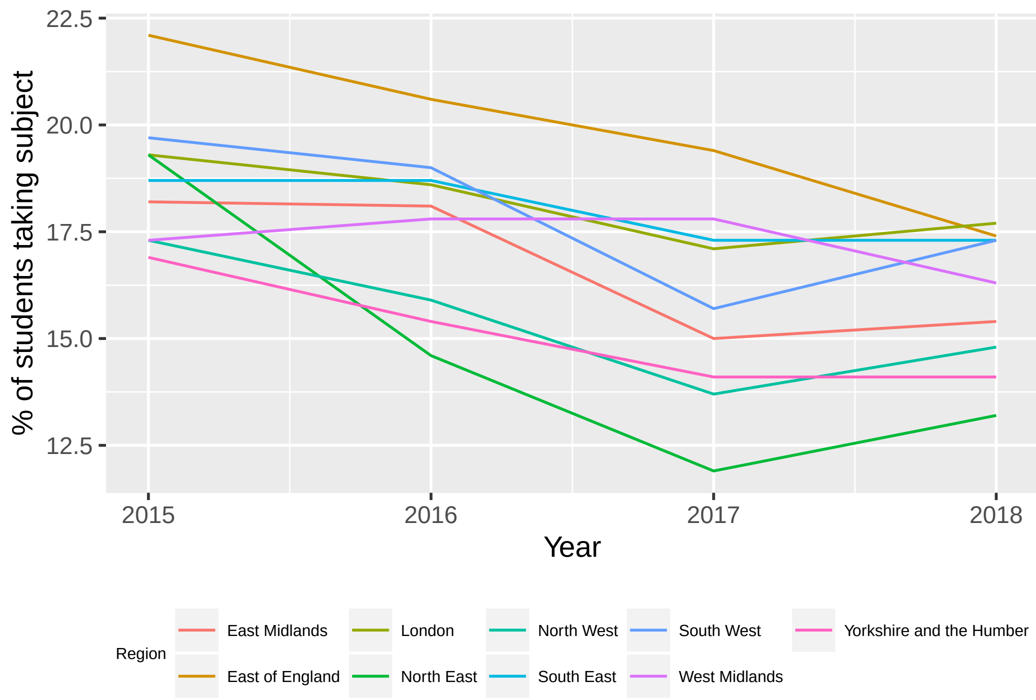

Figure 6.5: GCSE Media regional provision, by % of all students, 2015-18

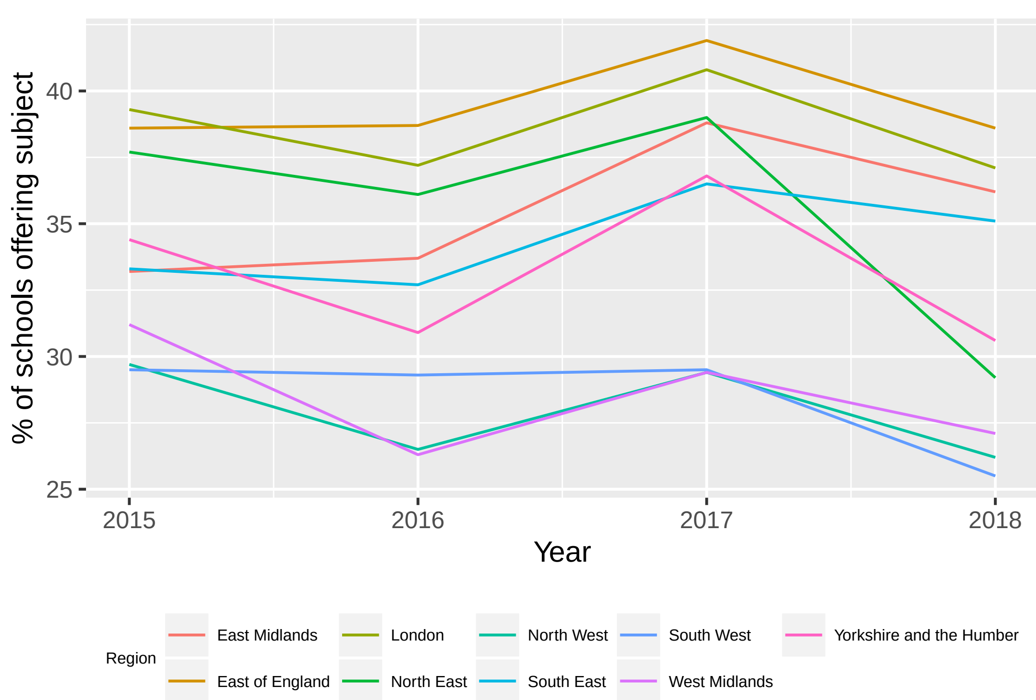

Figure 6.6: GCSE Media regional provision, by % of providers, 2015-18

6.5.5 Dropped schools

Amongst schools offering GCSE CS in 2017 the turnover rate is high, with 209 or 8.2% of schools dropping the qualification in 2018 (table 6.10). However, numbers of providers are up, with 321 new schools offering the course in 2018. Amongst those schools offering the qualification in 2017, 18.6% of girls-only comprehensives dropped the subject in 2018, compared to 1.3% of boys-only schools. Amongst girls grammar schools, 11.6% dropped the course, there were no instances of an all-boys grammar school dropping the course in this timeframe.

Media studies saw a steep decline in schools offering the subject, with 18.8% of schools offering the subject in 2017 no longer offering it in 2018 (table 6.11). The largest turnover was seen amongst mixed schools with 37.8% of independent and 18.0% of comprehensive schools dropping the subject in this timeframe.

Type	Gender	Total	Subject 18	Subject 17	dropped	dropped %	new	new %
Comprehensive	BOYS	89	79	77	1	1.3	3	3.8
Comprehensive	GIRLS	139	89	86	16	18.6	19	21.3
Comprehensive	MIXED	2591	2082	2030	133	6.6	185	8.9
Grammar	BOYS	55	47	41				
Grammar	GIRLS	59	45	43	5	11.6	7	15.6
Grammar	MIXED	47	38	36	2	5.6	4	10.5
Ind Special	BOYS	15	2	2				
Ind Special	GIRLS	4						
Ind Special	MIXED	157	6	3	2	66.7	5	83.3
Independent	BOYS	69	12	8	2	25.0	6	50.0
Independent	GIRLS	167	58	43	5	11.6	20	34.5
Independent	MIXED	550	192	175	39	22.3	56	29.2
Special	BOYS	39	3	2				
Special	GIRLS	2						
Special	MIXED	305	14	9	4	44.4	9	64.3

Table 6.10: Change in schools offering GCSE CS 2017-18

Type	Gender	Total	Subject 18	Subject 17	dropped	dropped %	new	new %
Comprehensive	BOYS	89	38	39	4	10.3	3	7.9
Comprehensive	GIRLS	139	58	60	8	13.3	6	10.3
Comprehensive	MIXED	2591	1135	1232	222	18.0	125	11.0
Grammar	BOYS	55	8	9	1	11.1	0	0.0
Grammar	GIRLS	59	4	4				
Grammar	MIXED	47	4	5	1	20.0	0	0.0
Ind Special	BOYS	15						
Ind Special	GIRLS	4						
Ind Special	MIXED	157	12	13	6	46.2	5	41.7
Independent	BOYS	69						
Independent	GIRLS	167	3	3				
Independent	MIXED	550	41	58	22	37.9	5	12.2
Special	BOYS	39	3	3	1	33.3	1	33.3
Special	GIRLS	2						
Special	MIXED	305	16	17	7	41.2	6	37.5

Table 6.11: Change in schools offering GCSE Media 2017-18

6.5.6 Subject hours

When looking at the number of hours of computing taught at school, there has been a steep decline across keystages 3, 4 and 5 since 2012 (figure 6.7). KS4 has decreased by 50.6%, KS5 by 39.8% and KS3 by 26.2%. KS3 figures leveled out between 2017 and 2018.

Between 2012 and 2018 media studies saw a decline in the number of hours taught at KS4 (down 26.2%) and KS4 (down 31.7%), but also an increase in the number of hours taught at KS3 (up 42.9%), albeit from a low starting position (figure 6.8).

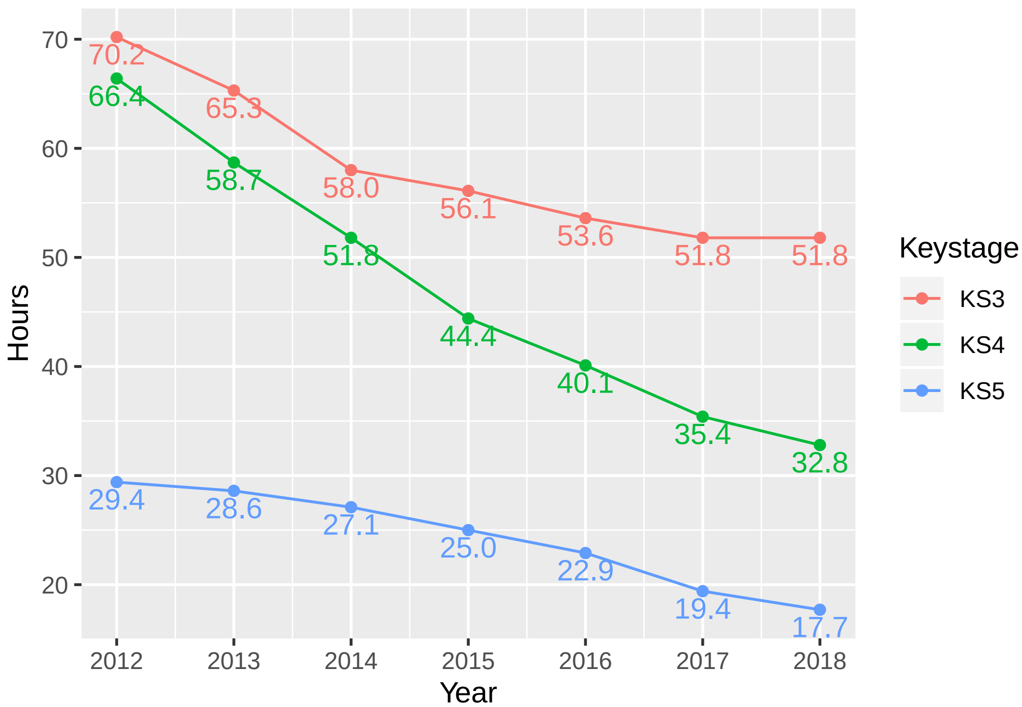

Figure 6.7: Total hours of taught computing per week (thousands)

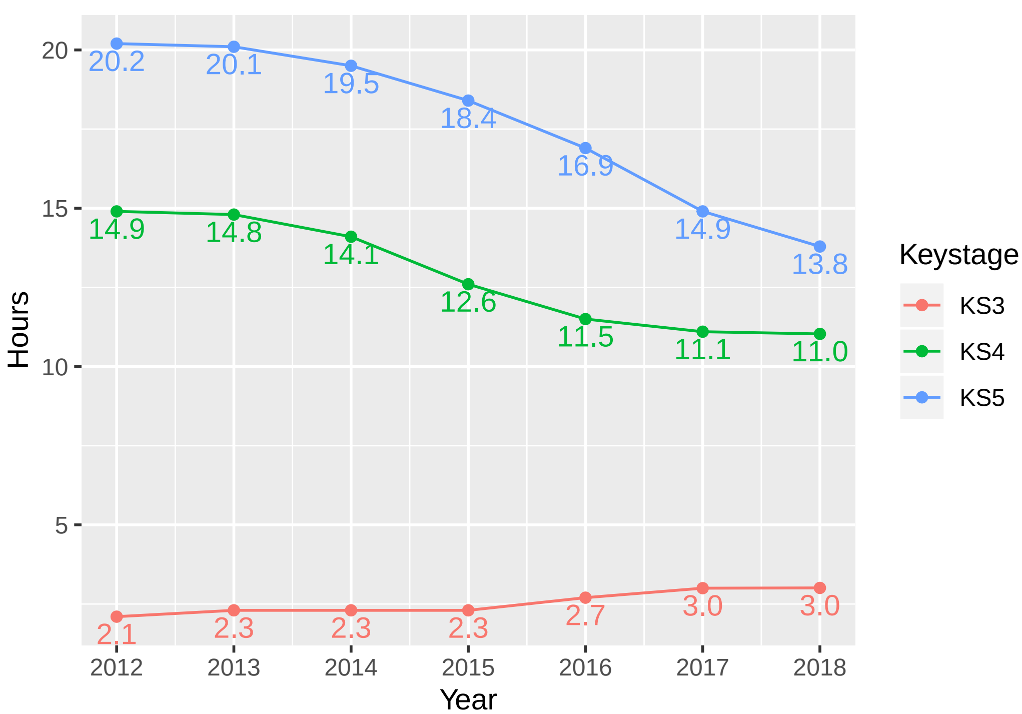

Figure 6.8: Total hours of taught media per week (thousands)

6.5.7 Uptake by IDACI and PP

Working class students are underrepresented in computer science cohorts (table 6.12). When combining pupil-premium with gender and ethnicity, I note that not all ethnic groups are equally underrepresented, with Chinese working class boys and girls being better represented than their middle class peers (boys 42.9% vs 41.4% and female 18.9% vs 15.7%).

Uptake of media studies was not so easily demarcated along poverty lines, with a mix of representations, including better representation for some working class groups than for their middle class peers, e.g. Black students (girls 16.1% vs 14.3% and boys 18.5% vs 16.2%).

The NPD records the ethnicity of students using the categories: Asian (ASIA), Black (BLAC), Chinese (CHIN), mixed (MIXD), White (WHIT), any other ethnic group (AOEG), undeclared and missing (UNCL)

Table 6.12: GCSE CS and Media uptake as percentage of school population by gender, ethnicity and pupil premium (PP)

		Computer Science		Media	
Gender	Ethnicity	non-PP	PP	non-PP	PP
F	AOEG	152 (10.9%)	87 (7.9%)	143 (14.8%)	127 (16.5%)
F	ASIA	1385 (12.0%)	492 (9.4%)	1075 (14.3%)	618 (16.1%)
F	BLAC	408 (8.8%)	299 (6.4%)	533 (16.7%)	669 (18.3%)
F	CHIN	98 (15.7%)	18 (18.9%)	34 (11.5%)	9 (14.5%)
F	MIXD	359 (7.1%)	156 (5.6%)	533 (16.2%)	340 (16.3%)
F	UNCL	84 (6.6%)	40 (7.7%)	114 (17.1%)	54 (16.4%)
F	WHIT	6363 (5.6%)	1835 (5.4%)	12127 (17.4%)	3583 (16.1%)
M	AOEG	417 (24.4%)	273 (21.2%)	151 (13.5%)	159 (17.5%)
M	ASIA	3657 (28.4%)	1379 (23.3%)	1191 (14.5%)	743 (17.1%)
M	BLAC	935 (18.9%)	812 (16.1%)	540 (16.2%)	683 (18.5%)
M	CHIN	259 (41.4%)	51 (42.9%)	54 (14.5%)	18 (21.7%)
M	MIXD	1364 (24.9%)	550 (18.8%)	573 (16.9%)	403 (19.6%)
M	UNCL	311 (23.9%)	120 (20.7%)	114 (17.4%)	56 (15.7%)
M	WHIT	30107 (24.9%)	6639 (20.1%)	12925 (17.8%)	3915 (18.2%)

Figure 6.9 places the GCSE CS and media populations into IDACI score deciles. I see that 7.2% of the

poorest females in schools offering CS are taking the exam, versus 5.0% of the richest females. Amongst the male population the trend is reversed with the richest males being more likely to take CS (24.8%) than the poorest (21.1%). Trend lines indicate positive correlation between female poverty and uptake in computer science, the reverse is seen for males.

For media studies the trend lines are far less conclusive with a slight correlation between richer females and their likelihood of taking media studies, 17.4% of the richest females take media, compared to 15.0% of the poorest.

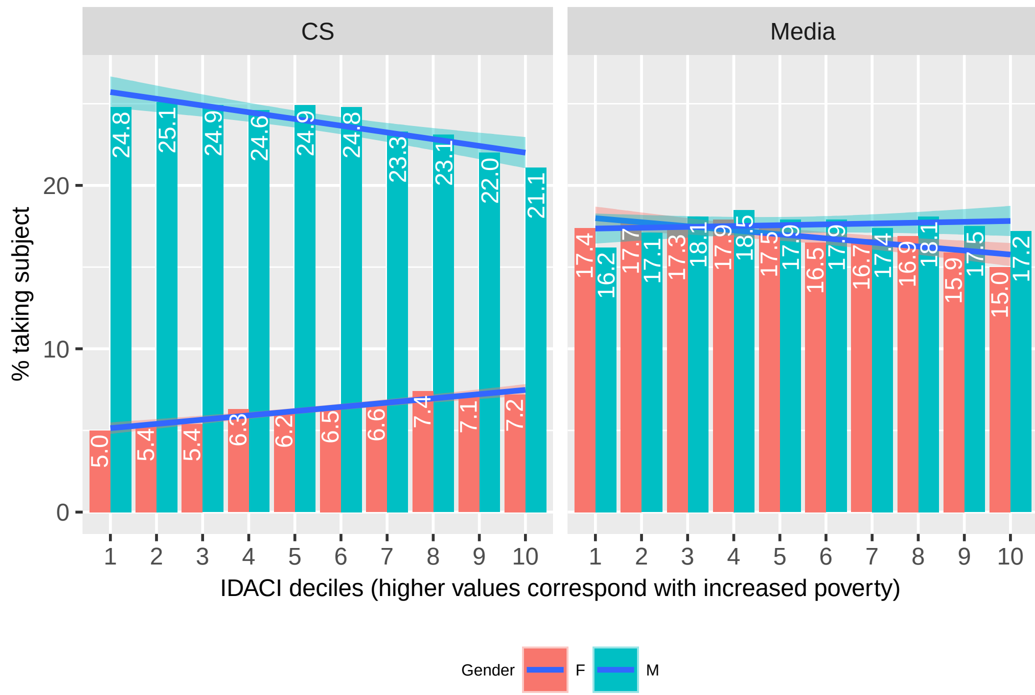

Figure 6.9: GCSE computer science and media studies, influence of IDACI on uptake by gender

Splitting the students taking CS by gender and applying a logistic regression model to look at the impact of IDACI on the chances of someone taking computer science (tables 6.13 and 6.14), we find that the poorer a female student is, the more likely she is to take computer science (b=0.832; $\chi^2(1)$=153.32, p=0.000), this is the reverse of relationship seen in the male population (b=-0.529; $\chi^2(1)$=180.57, p=0.000). Both models have very low R^2 values and whilst there is a significant difference, the effect size is very small and this model fails to explain most of the difference seen (Cox and Snell R^2: for female 0.001; male=0.001).

Table 6.13: Model: Females taking CS predicted by IDACI score

Estimate	Std. Error	z value	Pr(>|z|)
-2.8621	0.0166	-172.07	0.0000
0.8323	0.0664	12.54	0.0000

Table 6.14: Model: Males taking CS predicted by IDACI score

Estimate	Std. Error	z value	Pr(>|z|)
-1.0620	0.0090	-118.10	0.0000
-0.5285	0.0396	-13.35	0.0000

Performing the same calculations on the media studies population (tables 6.15 and 6.16) shows no significant relationship between IDACI and male uptake of the subject (b=0.0192; $\chi^2(1)$=0.12 , p=0.7311), there is a significant relationship within the female media group showing that poorer females are less likely to take media than their richer peers (b=-0.4295; $\chi^2(1)$=54.77, p=0.000), but again, the model has a very low R^2 value (Cox and Snell R^2: for female < 0.000; male < 0.000)

Table 6.15: Model: Females taking Media predicted by IDACI score

Estimate	Std. Error	z value	Pr(>|z|)
-1.5099	0.0137	-110.02	0.0000
-0.4295	0.0583	-7.36	0.0000

Table 6.16: Model: Males taking Media predicted by IDACI score

Estimate	Std. Error	z value	Pr(>|z|)
-1.5481	0.0133	-116.36	0.0000
0.0192	0.0559	0.34	0.7311

6.5.8 Uptake by IDACI and Ethnicity and Gender

When looking at the likelihood of someone taking GCSE CS and media by gender, ethnicity and IDACI quartile (figure 6.10), I note that the trend (as seen above) of poorer females being more likely to take CS than richer females does not apply to all ethnic groupings. For Asian, Black and Chinese females, the richest grouping was more likely to be sitting computing than the poorest grouping. Only Mixed ethnicity and White females show increased uptake amongst the poorest grouping, when compared to the richest grouping.

For media students, richer white, mixed and Chinese ethnicity students were more likely to take the subject than their poorest counterparts, the richest black students were less likely to sit the subject when compared to their poorer peers.

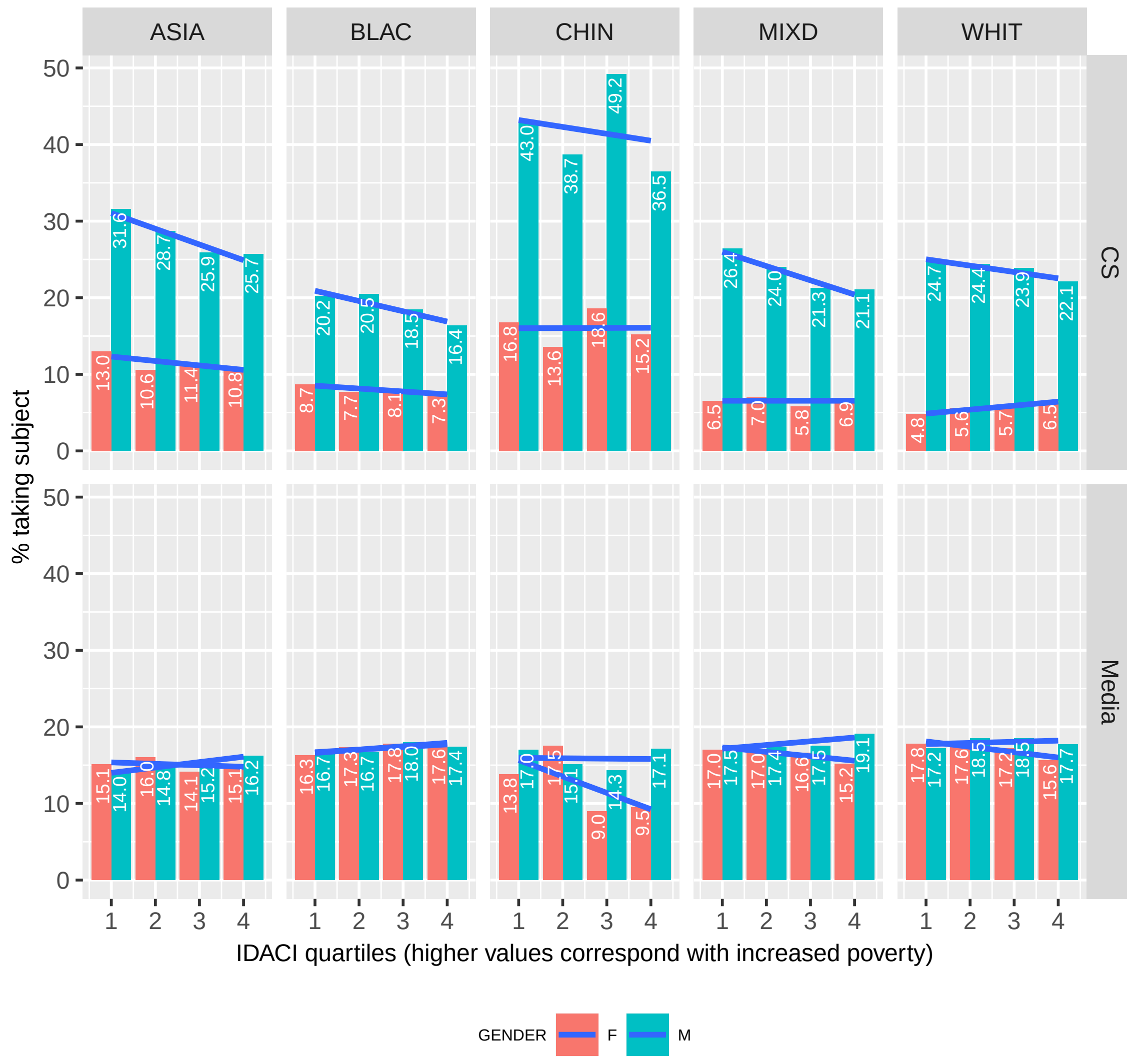

Figure 6.10: GCSE computer science and Media uptake, gender, ethnicity and IDACI quartile

6.5.9 Performance by gender

As noted earlier, females outperform males at GCSE CS, however, when you control for 'ability' by using the average grade in other subjects, males significantly outperform females (table 6.17). A multiple linear regression was calculated to predict CS grades based on average grade in other subjects and student gender. A significant regression equation was found for CS ($F(2,60673)= 47390$, $p < 0.000$) with an R^2 of 0.61. A participant's CS grade increased 1.22 grades for each single grade increase of average grade, and males scored 0.31 of a grade more than females. Both average grade in other subjects and gender were significant predictors of CS grade.

In contrast, the difference in media studies attributed to gender is the reverse (table 6.17), with being female explaining 0.41 of a grade more in the subject. A significant regression equation was found for Media (F(2,42115)= 31587, $p < 0.000$) with an R^2 of 0.60.

Male outperformance of females in computer science is only exceeded by results in mathematics (b=0.46; $p < 0.000$) and physics (b=0.41; $p < 0.000$), female outperformance of males in media is only exceeded by results in Art & Design (b=-0.47; $p < 0.000$).

		Avg Grade (SD)		Estimate of subject result predictors		
Subject name	n	F	M	Avg.Grade	Gender	R^2
Maths	521790	5.09(1.78)	5.00(1.86)	0.99***	0.46***	0.68
Physics	127800	6.17(1.24)	6.16(1.25)	1.06***	0.41***	0.71
CS	60736	4.87(2.05)	4.70(2.02)	1.22***	0.31***	0.61
Science Additional	347749	4.81(1.49)	4.55(1.54)	0.97***	0.24***	0.72
Science Core	246700	4.38(1.48)	4.14(1.50)	0.89***	0.22***	0.72
Physical Ed	110951	5.35(1.51)	5.03(1.41)	0.76***	0.21***	0.52
Chemistry	127545	6.26(1.25)	6.05(1.27)	1.07***	0.18***	0.72
Bus Studies	70892	5.03(1.72)	4.81(1.76)	1.18***	0.16***	0.70
Biology	125890	6.28(1.23)	6.04(1.26)	1.03***	0.14***	0.74
History	237045	5.28(1.94)	4.83(2.02)	1.26***	0.05***	0.73
Music	40138	5.57(1.64)	5.32(1.76)	0.87***	0.05***	0.53
ICT	67359	5.21(1.77)	4.75(1.84)	1.00***	0.02.	0.59
Geography	222742	5.34(1.83)	4.89(1.82)	1.15***	0.02***	0.77
Drama	65948	5.53(1.46)	4.96(1.55)	0.73***	-0.19***	0.50
German	46152	5.54(1.39)	5.15(1.45)	0.90***	-0.21***	0.54
D&T Res Mat	45511	5.41(1.70)	4.53(1.74)	0.88***	-0.24***	0.61
French	129414	5.43(1.52)	4.98(1.57)	0.92***	-0.25***	0.54
Spanish	83120	5.52(1.63)	5.03(1.71)	0.92***	-0.25***	0.47
English Lang	306514	5.63(1.32)	5.06(1.41)	0.78***	-0.26***	0.69
English Lit	372197	5.65(1.40)	5.00(1.53)	0.83***	-0.32***	0.70
Relig Studies	246302	5.66(1.79)	4.91(1.97)	1.08***	-0.38***	0.69
Fine Art	48590	5.76(1.48)	4.98(1.65)	0.66***	-0.39***	0.48
Media/Film/Tv	42115	5.46(1.51)	4.59(1.61)	0.88***	-0.41***	0.60
Art & Design	77963	5.60(1.50)	4.64(1.61)	0.63***	-0.47***	0.48

Table 6.17: GCSE grade outcome predicted by average GCSE grade and gender

6.5.10 Relative performance against other subjects

Both genders typically performed worse in CS than nearly all of their other subjects (table 6.18). Females only performed better in CS than in German, and males only performed better in CS than in German, French and Spanish.

There were 3,905 (Male=3,158; Female=747) who took both computer science and Media GCSEs in 2016. Both groups typically performed worse in CS than in Media (Male: M=-0.87 SD=1.74; Female: M=-1.44 SD=1.49), with the difference in average female grades being greater than any other subject combination.

A multiple linear regression was calculated to predict grades in other subjects based on CS grade and student gender. A significant regression equation was found for Media ($F(2,3158)=1375$, $p < 0.000$) with an R^2 of 0.32. A participant's Media grade increased 0.39 grades for each single grade increase in CS, and on average males scored 0.72 of a grade less than females. Both CS grade and gender were significant predictors of Media grade.

A multiple linear regression was calculated to predict grades in other subjects based on Media grade and student gender. A significant regression equation was found for CS ($F(2,3158)=1540$, $p < 0.000$) with an R^2 of 0.29. A participant's CS grade increased 0.73 grades for each single grade increase in Media, and on average males scored 0.35 of a grade more than females. Both Media grade and gender were significant predictors of CS grade.

There was not a single subject where females, on average, got a higher grade in that subject than in media (table 6.19). The closest subjects being Art & Design (*M*=0.03(*SD*=1.38)) and English Literature (*M*=0.06(*SD*=1.08)). The difference in grade between the average CS and media female was *M*=1.44(*SD*=1.49), the next biggest difference was for German (*M*=0.97 *SD*=1.29).

Gender was a much larger predictor of grade differences between computer science and the arts subjects (e.g. Fine Art (-0.80***), English Lit (-0.57***)), than it was between computer science results and the STEM subjects (e.g. Physics (0.10***), Maths(0.07***)).

Table 6.18: Average difference between GCSE computer science results and other subjects, by gender. Positive mean values signify students doing better in CS. Positive gender predictor values indicate males doing better

Subject name	Male		Female			predictors of subject grade		
	n	M(SD)	n	M(SD)	Diff	CS grade	Gender	R^2
German	5001	0.39(1.43)	1267	0.05(1.27)	0.34	0.49***	-0.47***	0.36
Music	2916	-0.17(1.65)	884	-0.30(1.50)	0.13	0.49***	-0.24***	0.35
French	9449	0.27(1.56)	3274	-0.30(1.43)	0.57	0.47***	-0.61***	0.33
Physics	16759	-0.65(1.19)	4187	-0.37(1.07)	-0.28	0.51***	0.10***	0.45
Biology	16299	-0.47(1.21)	4151	-0.43(1.07)	-0.03	0.49***	-0.14***	0.45
Chemistry	16756	-0.46(1.21)	4210	-0.43(1.07)	-0.03	0.51***	-0.13***	0.45
Spanish	6089	0.14(1.64)	2069	-0.50(1.50)	0.64	0.49***	-0.70***	0.32
Bus Studies	7440	-0.43(1.47)	1290	-0.54(1.38)	0.11	0.57***	-0.17***	0.45
Geography	18004	-0.41(1.43)	4299	-0.64(1.32)	0.23	0.56***	-0.34***	0.49
History	18456	-0.39(1.49)	4684	-0.65(1.38)	0.26	0.61***	-0.36***	0.47
Physical Ed	7002	-1.01(1.73)	1140	-0.72(1.61)	-0.29	0.36***	-0.06.	0.28
English Lang	26935	-0.39(1.52)	7310	-0.73(1.43)	0.34	0.40***	-0.47***	0.40
Drama	2682	-0.62(1.79)	1181	-0.86(1.66)	0.25	0.36***	-0.45***	0.28
D&T Prod Des	4290	-0.37(1.58)	543	-0.86(1.41)	0.48	0.52***	-0.70***	0.42
ICT	3727	-0.77(1.42)	417	-0.93(1.34)	0.16	0.60***	-0.20**	0.51

English Lit	33374	-0.49(1.55)	8799	-0.94(1.49)	0.45	0.42***	-0.57***	0.41
D&T Res Mat	4949	-0.77(1.64)	369	-0.99(1.52)	0.22	0.48***	-0.52***	0.41
Science Additional	27148	-0.98(1.44)	6963	-1.02(1.39)	0.04	0.48***	-0.08***	0.46
Maths	45002	-1.17(1.44)	11442	-1.02(1.37)	-0.15	0.51***	0.07***	0.49
Science Core	17117	-1.08(1.50)	4394	-1.09(1.47)	0.01	0.42***	-0.03.	0.41
Relig Studies	19867	-0.45(1.61)	5964	-1.10(1.52)	0.65	0.53***	-0.72***	0.41
Art & Design	2772	-0.74(1.93)	1870	-1.28(1.80)	0.53	0.32***	-0.85***	0.31
Fine Art	1819	-0.75(1.86)	1198	-1.30(1.79)	0.55	0.33***	-0.80***	0.32
D&T Food Tech	1159	-0.67(1.65)	603	-1.30(1.58)	0.63	0.45***	-0.89***	0.48
English Lang Lit	1914	-0.83(1.58)	361	-1.43(1.47)	0.59	0.34***	-0.30***	0.30
Media/Film/Tv	3158	-0.87(1.74)	747	-1.44(1.49)	0.57	0.39***	-0.72***	0.32
CS	48348	0(0)	12388	0(0)	0			

Table 6.19: Average difference between GCSE Media results and other subjects, by gender. Positive mean values signify students doing better in Media. Positive gender predictor values indicate males doing better

	Male		Female			predictors of subject grade		
Subject name	n	M(SD)	n	M(SD)	Diff	CS grade	Gender	R^2
CS	3158	0.87(1.74)	747	1.44(1.49)	-0.57	0.73***	0.35***	0.29
German	1019	0.75(1.38)	1286	0.97(1.29)	-0.22	0.49***	-0.10*	0.25
French	2847	0.80(1.39)	4339	0.90(1.31)	-0.10	0.56***	-0.18***	0.29
Bus Studies	3094	0.42(1.34)	2061	0.85(1.28)	-0.43	0.78***	0.28***	0.44
History	8153	0.56(1.44)	8394	0.76(1.35)	-0.20	0.91***	0.12***	0.49
Music	1026	0.17(1.57)	1012	0.75(1.45)	-0.58	0.59***	0.28***	0.30
Spanish	2132	0.70(1.64)	2860	0.72(1.50)	-0.02	0.53***	-0.28***	0.23
Physical Ed	4659	-0.13(1.39)	1723	0.72(1.33)	-0.85	0.47***	0.30***	0.29
Geography	7587	0.44(1.31)	6481	0.71(1.23)	-0.26	0.79***	0.09***	0.49
Science Core	11610	0.10(1.31)	9987	0.71(1.21)	-0.61	0.54***	0.22***	0.40
Science Additional	15784	0.15(1.33)	15079	0.70(1.19)	-0.56	0.57***	0.19***	0.38
Physics	2894	-0.02(1.23)	2873	0.70(1.14)	-0.73	0.50***	0.33***	0.24
Maths	20683	-0.14(1.46)	19239	0.61(1.32)	-0.75	0.62***	0.43***	0.36
Chemistry	2842	0.09(1.23)	2822	0.60(1.11)	-0.50	0.53***	0.14***	0.27
Biology	2794	0.07(1.20)	2790	0.56(1.09)	-0.49	0.54***	0.12***	0.29

ICT	3365	0.09(1.47)	1963	0.47(1.39)	-0.38	0.75***	0.16***	0.39
D&T Prod Des	1596	0.38(1.46)	524	0.37(1.35)	0.01	0.64***	-0.37***	0.40
Drama	2193	0.12(1.41)	2675	0.33(1.27)	-0.22	0.58***	-0.11**	0.37
D&T Res Mat	2009	0.11(1.39)	236	0.30(1.38)	-0.19	0.62***	-0.13	0.37
Relig Studies	7606	0.37(1.44)	8349	0.26(1.33)	0.11	0.79***	-0.28***	0.47
English Lang	10225	0.03(1.14)	11037	0.21(1.07)	-0.18	0.57***	-0.15***	0.48
English Lang Lit	1598	-0.13(1.19)	774	0.11(1.18)	-0.25	0.48***	-0.01	0.43
D&T Food Tech	702	0.15(1.37)	1035	0.08(1.15)	0.07	0.62***	-0.44***	0.47
Fine Art	939	0.03(1.48)	1937	0.07(1.32)	-0.04	0.53***	-0.41***	0.37
English Lit	13984	-0.02(1.17)	14247	0.06(1.08)	-0.09	0.61***	-0.23***	0.51
Art & Design	1420	-0.01(1.49)	3233	0.03(1.38)	-0.04	0.49***	-0.40***	0.33
Media/Film/Tv	21872	0(0)	20243	0(0)	0			

6.6 Discussion

This first research study looks to answer the question: *What characterises the opportunities for learning 3D animation in the formal curriculum?*. To do this I looked at student uptake, access and performance in computer science and media studies. This links to broader questions around creativity, where using the systems model of creativity (Csikszentmihalyi, 2013), students can become creative by increasing their efficacy in domains of knowledge through studying courses at school. With access to these courses being limited by the curriculum offer in schools, students not taking up opportunities to study courses when they are offered, and student performance being predicted by student gender, I paint a picture of the inequalities that face students taking formal courses that align with domain skills involved in 3D digital animation.

6.6.1 Access and participation

Overall access to GCSE computer science has been increasing since 2015, with 61.3% of schools offered the subject and 79.2% of students being in a school where the subject was offered in 2018. An increase is not surprising, as the course was newly introduced in 2014 (Kemp et al., 2016), and whilst the numbers are increasing, they remain below the number of students who were taking another digitally focused GCSE ICT in 2015 (Kemp et al., 2018). Access to GCSE media studies decreased over the same time period, with 30.3% of schools offering the subject in 2018 compared to 33.9% in 2015, more worrying perhaps is the decrease in numbers of students taking the exam, dropping from 8.9% in 2015 to 7.4% in 2018.

6.6.1.1 Subject hours Overall the number of hours dedicated to computing and media teaching in secondary school, where computing encompasses GCSE CS and other digital courses, has decreased substantially since 2012. Computing has seen a 50% drop at KS4, with media seeing a 31.7% drop. The decline matches and brings up to date figures produced by Worth & De Lazzari (2017), which failed to give such fine grained analysis, with computer science hours categorised under "technology" courses and media studies categorised under the "Arts". This decline in taught hours is likely related to the importance schools place on the subjects now that schools are being held accountable to the *progress 8* measurement (Steers, 2014); mathematics and English, the two most important subjects in progress 8, have seen increases the number of hours taught, as have history and geography which make up another component of progress 8 (Worth & De Lazzari, 2017, p. 7). GCSE media counts as one of the EBacc "other" courses, making it directly compete against a wide range of subjects including Drama, Art and D&T for space in the curriculum; with students being unlikely to pick more than one of these courses. Whilst GCSE CS can be used in the English Baccalaureate as a replacement for a single science, i.e. physics, chemistry or biology, using the subject in this way is unusual (Kemp et al., 2018). As mentioned above, the number of GCSE CS students has been increasing, so the decline in hours might be better attributed to a decline in other computing qualifications such as the vocational courses (Kemp et al., 2018). More worrying, perhaps, is the decline in KS3 computing provision, which has seen a decrease of 26.2% since 2012. KS3 does not have set computing examinations, and this decline suggests an overall decline in general computing provision for KS3, i.e. *all*, students.

If the domain knowledge for computing and media studies is not easily accessible within student's own social circles, i.e. it is *powerful knowledge* (Young, 2007), and students rely on formal education and teachers for this knowledge (e.g. Sefton-Green & Brown, 2014). A decrease in time provided to computing and media would suggest that students will either be getting less time to pick up these skills, or for some, no time at all. In a society increasingly dominated by new media and computing, the lack of skills and knowledge in these domains will hinder students in becoming active and critical members of society (one of the aims of a media education e.g. Buckingham, 2003). Csikszentmihalyi (2013, p. 8) observes that creativity involves "surplus attention"; with teachers and students short of time and creativity often needing a "long incubation period", this makes creativity, digital or not, less likely in the classroom (Steers, 2013, pp. 168–9). There is no indication that the content of computing has been reduced over the last few years that coincide with decline, in fact it is quite the opposite, the 2014 computing curriculum incorporates most of the old ICT curriculum and adds computer science (Kemp, 2014b). The reduction in the number of hours of KS3 computing suggests that students are either getting less time for the same material, reducing the chances of them having the "surplus attention" to be creative, or they are having cut down content delivered, reducing their chances of mastering the domain of knowledge needed to be creative.

6.6.1.2 Computer science gender, ethnicity and poverty When categorised by pupil premium, of all girls taking computer science, female working class students show a higher relative representation than working class boys (24.9% vs 21.0%), but this falls short of being representative of the population (26.8%) (Kemp et al., 2018) (Table 6.12). White working class female students showing the poorest representation overall in CS (5.4%) (Table 6.12). Chinese working class girls are the best represented group amongst GCSE female computer science students; this pattern of increased working class representation does not map to other ethnic minority groups (Table 6.12). However, we should note the small cohort size here (n = 116) when compared to other ethnic groups. In 2016 there were areas in England with close to 50% female representation in GCSE CS (Kemp, 2017), many of them local authorities having a minority of white British students. Cultural factors might partially explain the better representation of ethnic minority girls, where 'professional' careers, including IT, are typically considered as a 'safe' choice for minority families, with perceived better or more stable financial returns (Archer et al., 2014b; Wong, 2016b).

In contrast to the findings that working class (defined by pupil-premium) students are less likely to take computer science than their richer (non-pupil-premium) peers, the more fine-grained poverty indicator IDACI, suggests that amongst girls taking computer science, poverty is positively correlated with uptake (Table 6.13; figure 6.9). This is not the picture amongst boys, where the poorer are less likely to be studying CS (Table 6.14; figure 6.9). Working class girls or their families might perceive CS as a subject with the potential to offer greater returns, with public discourse on the growing importance of technology in everyday life, including successful narratives of individual upward social mobility through digital entrepreneurship (e.g. British Computer Society, 2018). Why this picture emerges for girls and not boys remains unclear. This might be an indication that the message about computer science being a subject for girls is being received less enthusiastically by middle class girls than their working class peers; with both groups being less receptive than the male population.Whilst the relative representation of working class girls compared to middle-class girls is better than that seen for boys, far more working class boys took computing than their female peers (n = 9,824 vs n = 2,927).

Breaking down the gender IDACI model into separate ethnic groups (figure 6.10) showed that increased uptake amongst the poorest students does not apply to Asian, Black and Chinese females. The trend of poorer females being more likely to take CS is heavily influenced by the large cohort of white female students, where the poorest are most likely to take the subject. While the white working class female population appears to be better represented than the white middle class female population, the percentage of white working class girls still trails other ethnic groups, as noted above. Additionally, using poverty indicators and gender to predict the uptake of computer science explains little of the variance seen (seen through low effect sizes); there are clearly other factors at play and further research is merited here.

6.6.1.3 Media studies gender, ethnicity and poverty Findings for media studies (Table 6.12) show uptake much more evenly balanced between working class and middle class students (specified here as being pupil premium or non-pupil premium). But when looking at the more finely grained poverty indicator, IDACI, poorer girls were less likely to be taking media studies than their richer peers (figure 6.9 and Table 6.15). There was no significant difference for males. Looking within the female cohort I find an under representation of Chinese girls, with other ethnic groupings showing roughly the same uptake (figure 6.10). There is currently a lack of literature on uptake of media qualifications at this level, restricting the analysis I can do here. If we take media studies to be more aligned to the arts and humanities than STEM subjects like computer science, and see females to be more likely to pick arts and humanities subjects as they align more closely with female characteristics (e.g. *empathising versus systemising* Baron-Cohen, 2004), then we might expect that the subject would be more popular amongst females. This isn't the case, with roughly equal gender uptake (figure 6.9).

6.6.1.4 Regional and institutional offerings The percentage of schools offering GCSE computer science (Table 6.8) varies between 65%in the East of England and 57% in London. More concerning are student numbers, which have seen decreases in for some regions since 2016: North East (~14.5% down to ~13.3%), South West (~15.6% down to ~15.0%) and Yorkshire and Humber (~14.3% down to ~13.8%). Other regions saw increases over this time period. The decline of computing in some areas supports the Royal Society's (2017) claim that computing education is "is patchy and fragile" (p.6). All girls schools appear to have the greatest flux in provision, with nearly 20% of all girls comprehensives dropping the course between 2017 and 2018. This correlates in with gendered ideas of computer science, where girls schools that offer CS finding there isn't the demand or the resources to run it. However, actual reasons for this decline are unknown and further research is merited here. Provision in grammar (81.0%) and comprehensive schools (79.7%) appears to be about equal, though grammar school students are far more likely to take up the subject (19.8% vs 12.8%) suggesting grammar schools are more likely to be running larger or more classes per year group.

Overall media studies is in decline, with all regions showing fewer students studying the subject in 2018 than in 2015. The most affected region is the North East that saw student percentages dropping from ~19% to 15%. Overall students in comprehensive schools (~43.2% of schools) are far more likely to be in an institution that offers Media studies, than their peers in private (5.5%) or grammar schools (9.8%). There appears to be a social divide in provision emerging that has a class dimension. This overall decline in provision of media studies is particularly worrying when society is increasingly influenced by media products (e.g. Burn & Parker, 2003)

6.6.2 Performance

Girls do better than boys when taking GCSE CS (Kemp et al., 2018), however, girls significantly underperform in computer science compared to boys when controlling for their achievement in other subjects (Table 6.17). Female relative underperformance in computer science is less than that in mathematics and physics. This contrasts with findings around performance at university level, where females did worse at highest grades in CS than in mathematics and physics (Wagner, 2016). Amongst students taking GCSE media studies, the relationship is the inverse seen in CS, with females on average achieving 0.41 of a grade more in media than their male counterparts when controlling for their 'ability' in other subjects.

Relative underperformance might be explained by the different subjects boys and girls take. Some courses are considered easier to score high grades in than others, with STEM subjects being amongst the more difficult (Bramley et al., 2015; Office of Qualifications and Examinations Regulation, 2015), and STEM subjects also being more popular amongst boys (Joint Council for Qualifications, 2016). This would bring an average male CS result closer to that of their other subjects, whilst an average female CS result would diverge from their other results. This might help explain some of the 0.31 of a grade difference seen in CS. However, direct comparisons between CS grades and media and English grades show significant differences between genders; my model showed that amongst GCSE computer science students, gender explained, 0.47 of a grade in English Language, 0.57 of a grade in English Literature and 0.72 of a grade in media (Table 6.18). These differences when controlling for attainment in CS suggest that the 0.31 isn't entirely down to subject choice. More work on subject choice and grades is needed here.

Students appear to be getting high grades in GCSE media studies compared to their other subjects, with females getting a higher average grade in media than all the other subjects that they took at the same time (Table 6.19). Females taking computer science and media on average got 1.44 grades higher in media studies than they did in computer science, this was the largest difference out of all the subjects compared. For boys, the difference was a much smaller 0.87 of a grade.

Overall reasons for female relative underperformance in CS and overperformance in media remain unclear, but likely involve a combination of subject choice, social (as discussed above) and psychological factors. Psychological factors around increased male self-efficacy (Huang, 2013), spatial intelligence (Fincher et al., 2006) and systemizing (Baron-Cohen, 2009) suggest that boys would outperform girls in GCSE CS; this clearly isn't the case when looking at raw grades (Table 6.17). But in a system where girls achieve more highly in general, these factors might help explain female relative underperformance in CS. Female strengths lying outside STEM subjects (Stoet & Geary, 2018) might help explain their outperformance of males in media studies.

The testing of these psychological hypotheses is beyond the scope of this thesis, but they warrant further research into their impact on attainment in computer science and media studies.

The difference in performance between media and computer science grades is greater for girls than boys, meaning that amongst girls and boys of the same 'ability' in computer science, girls would on average go on to achieve 0.57 of a grade more in media. Male and female CS results compared against English results see girls significantly outperforming boys at English, supporting findings for girls being stronger in verbal skills, and boys finding their strength in STEM subjects (Stoet & Geary, 2018; Wang et al., 2013). These differences are important for female self-efficacy, where comparisons might be made to male students of similar abilities and/or their own results in other subjects. Building on Pajares and Schunk's (2002) finding that prior achievement links to subject choices and theories about subject choice in more gender equal countries such as England being heavily influenced by relative strengths (Stoet & Geary, 2018), it follows that this relative female underperformance in GCSE CS will make it less likely for a female to pursue further study or a career in computing, and female over performance in GCSE media studies might persuade more females to study media at A-level and beyond. A-level media studies entries for 2018 (Joint Council for Qualifications, 2018a), two years after the 2016 GCSE results that I study above, show 56% of entries were female, higher than the entry pattern for GCSE (47% female (Joint Council for Qualifications, 2018b)). The extent to which relative strength influences subject choice needs to be studied further.

6.7 Conclusion

One of the premises of this research is to look at the main subject domains that make up 3D animation, picking media studies and computer science as the two focal subjects. Whilst this choice might be queried, there are clear differences in the uptake and performance of males and females taking these subjects. Burn (2013) argues that a curriculum built on subject domains "cuts across the multimodal relationships of authentic cultural forms like film and games, and each domain tends to privilege its own modes" (p.320), and there is a fear here that a media studies course without computer science and a computer science course without media studies will help reinforce existing digital and media creation divides.

Where computing and media studies content can be argued as being *powerful knowledge* (Young, 2007) we find that overall hours for both subjects have been reduced, with schools focusing on other subject areas. This overall trend hides inequalities in access where poorer students are less likely to be getting a computer science education than their richer peers and females are less likely to study computer science, even when the subject is offered in their school. This supports previous predictions that the introduction of computer science would create an exclusive subject area (Rudd, 2013). Media studies sees grammar school students far less likely to be studying the subject, which raises questions, to be answered elsewhere, about the level of Media literacy amongst middle class students.

With reduced hours meaning a more limited curriculum and/or decreasing numbers of students taking any form of computing qualification, students look less likely to have formal support in being digitally creative than they were several years ago. Whilst there are encouraging reports about increasing numbers of students teaching themselves digital making skills at home (e.g. Ito et al., 2009; Quinlan, 2015), reductions in formal educational opportunities mean that students without the middle class, cultural and teacher led support to engage with these digital making opportunities, as outlined by Sefton-Green & Brown (2014), will likely miss out.

There are other more equitable computing qualifications available beside the GCSE (Kemp et al., 2018), many of them including digital media elements, and making them closer to STEAM than STEM. The majority of girls still outperform boys in CS and the new computing curriculum in England has only been around since 2014 (DfE, 2013). The impact of prolonged study of the subject before selecting to take it between 14 and 16 needs to be explored, as do the reasons for female relative underachievement in computer science. Further analysis is needed here of learning pathways between qualification levels, more specifically how does relatively weak performance at 16 impact self-efficacy, subject choice for college and university, and choice of career?

Vitores and Gil-Juárez (2016) argue that we must look at the way we imagine computing, not just looking at ways to engage girls with our current conceptions. If the main computing qualification at age 16 in England is currently more attractive to one gender than another, and if one gender currently finds their strength in it and not the other, we should not wait for classroom pedagogy, society and individual characteristics to change, as to do so risks disenfranchising hundreds of thousands of girls from a *computing* education. Where females outperform males at media studies we should make a similar argument, how can we change media studies to be more inclusive of males? Would broadening of both subjects to a middle ground with digital arts and computing skills combined lead to better participation and more equal performance?

7 Study 2 - 3Dcamp: computational thinking, creativity and multimodality from the students' point of view

7.1 Introduction

The aim of this thesis is to understand the role of 3D animation in supporting the development of digital creativity. Existing research in this area is limited and suggests diverse learning paths (Sefton-Green & Brown, 2014), and, whilst data exists on employment (O'Connor, 2018), literature on young 3D animators is lacking. Study one outlined factors that correspond with formal education pathways linked to 3D animation. Study two expands on this, outlining background information about young 3D animators and describing the domain component (Csikszentmihalyi, 2013) of 3D animation for digital creativity. By doing this it describes how the affordances of 3D animation are influenced by student social and cultural backgrounds, as well as hardware, software and the discourse of the 3D animation camp.

Throughout this research I refer to the 'systems model' of creativity as defined by Csikszentmihalyi (2013). Using the strands of *field*, *domain* and *person*, I map out the opportunities available and choices available for these digital makers. Within the *field* strand I look at the network of individuals that a student has access to, including their immediate family and friends, as well as teachers and how each of these groups had influenced them in their decisions and development. I explore the range of qualifications available and the choices behind student subject choice; as well as perceived and planned career trajectories. The *domain* allows me to look at the knowledge base of students and how they acquired this knowledge. Within the domain I explore computational thinking concepts and the role of multimodality in student work. I explore student access to software tools and their reasoning for software choices. Looking at each *person*, I enquire into their understanding of creativity and how they go about being digitally creative.

Through the analysis of 14 interviews with producers and directors attending the 3Dcamp, I attempt to better understand the role of 3D animation in supporting the development of digital creativity. In particular I answer the questions: *What are the affordances of 3D digital animation work for young people?* and *What possible connections are there between computational thinking and multimodality in the production of 3D digital animation?*

7.2 Methodology

The main aim of this study is to look at the affordances of 3D animation and the relationship between computational thinking and multimodality. To do this I will be undertaking qualitative data collection through the deployment and analysis of interviews. Interviews were chosen as the method of data collection, as the purpose of the study was to collect in depth perceptions and views.

Knowledge about the world can be argued to be objective or subjective. Positivism argues that there are objective truths about the world that a researcher can discover, truths that will always be true, independent of the circumstances and time that they are discovered (Bourdeau, 2018). Social constructivism argues that truth is subjective, as it is situated within the world, interpreted by individuals who come with their own prejudices, and is subjective by its nature (Steup, 2018). Study two involves working with students from very different backgrounds, their knowledge and experiences will be based on their social and cultural circumstances. In studying their perspectives any claim to truth, will be a claim to a truth within a particular situation, mediated by historical and social contexts (Burr, 2003). It therefore makes sense that, for the purposes of this study, I will be taking a social constructivist position as this will allow me to not only find out about young 3D animators, but also to situate their participation in digital creativity within the context of their own personal circumstances, including their backgrounds and prejudices.

Interviews are seen as more likely to elicit personal responses from interviewees (Cohen, Manion, & Morrison, 2012). Several different interview models are available and I have chosen to conduct semi-structured interviews. My literature review has revealed a range of concepts and theories which I would like to explore. However, I have also noted that the literature around 3D animation education is lacking so constraining any interviews to a set of predefined rigid questions might not allow for the insights students have to offer to come to the fore. Structured interviews generally offer a set range of responses and using this method would confine the research to my own preconceived ideas (Bryman, 2008). Unstructured interviews provide very little in the way of an agenda, in some cases following more of a conversation style research process following some initial starting questions (May, 2003). This method can lead to deep and detailed insights (Burns, 2000), but I argue that it is unsuited for this research study as I am bringing into the interview a range of initial understandings based on current research that I would like to expand on contest. I believe that the most suitable interview model is the semi-structured interview. The questions in this type of interview were predominantly open questions with room for the interviewer to further expand on and explore student answers. Based on an initial set of themes, it allows for the researcher to explore student's experience beyond a pre-set narrow selection of questions (Creswell, 2014; Rubin & Rubin, 2005).

Additionally, I will also be making reference to the quantitative data from study one, where I will be adding context to the statistical findings around student participation and performance in computing and media studies courses. This will involve a mixed methods approach, adding qualitative data to help interpret the initial quantitative findings, thus complementing the results of study one (Cohen et al., 2012).

7.2.1 Participants

All fourteen participants in the interviews had successfully applied for the animation camp. This meant that they had all demonstrated knowledge and skills using the Blender animation tool prior to the event, and, as such, the group were self selecting. Preliminary interviews were conducted with a range of students attending the camps and, originally, all 29 students were to be interviewed. However, the interviews failed to give responses that covered the full scope of the research, in particular the computing concepts of computational thinking and the semiotic processes involved in film creation. Many of the students were performing very specific functions for their teams and unable to comment in depth on these topics. I decided to focus the interviews on students directly involved with a range of semiotic and computational thinking decisions, i.e. those serving as directors and producers. Thus the interview process used "purposive" and "convenience" sampling (Cohen et al., 2012, pp. 156–158). I considered these students to have a better grasp of the decisions being made than their colleagues who took on a much more *directed* role. For example, a director or producer should have a knowledge of how each part of the film was put together and/or the technical and artistic difficulties and decisions involved; a student assigned the job of making multiple trees over the course of 3 days would probably have only used a limited set of tools and had a much more limited ability to shape the artistic and technical direction of the film. This thinking matches Sefton-Green & Brown (2014) who state that "what is deemed 'creative' work is not necessarily so[...] Clearly, there is a world of difference between the potential for aesthetic autonomy offered to, say, the artistic director overseeing the design of a computer game, and the games artists responsible for the practical realisation of someone else's ideas" (p.28). The original interviews are included in this study as they do cover other important areas of digital creativity.

Interviews were conducted with 12 students in total, four females and eight males, this reflects wider social inequalities seen in female access to and participation in digital making activities (e.g. Quinlan (2015); Kemp et al. (2018); and study one, above). It should also be noted that the percentage of females interviewed is lower than in the summer camp, as fewer females take up the management roles of director and producer. The reason for this is not explored here. There were five ethnic minority students out of the twelve, which is below the ethnic makeup of London (Kemp, 2017), the location of the camp, but students included were, in one case, from another country and three other cases from other parts of the UK. Only three of the students could be considered working class according to parental education and occupation, these students being of particular interest in terms of the pathways they had taken to become digitally creative, as such pathways less available to those from poorer backgrounds due to limited access to adult support (Sefton-Green & Brown, 2014).

Eight of the students were 18 years old, with the four other students being 12, 13, 14 and 16. Students came from a range of educational backgrounds, including one from a grammar school, another from a sixth form college, one from a private school and eight other students from comprehensive schools. This allowed us to focus on career and subject choices either made or pending for GCSE/A level/BTEC and University. Two of the students came from Boys only schools, with the rest coming from mixed-sex institutions. During the animation camp three of the students served as directors, five students served as producers, and four served in other roles. It is often the case on the camp that there is more than one producer for each team, whilst there is normally only one director, this explains the unbalanced number of interviewee type.

Due to the self selecting nature of the student body on this course, this research doesn't claim to be socially representative of all young 3D animators let alone all digitally creative youth, such representation with such detailed interviews would be impossible within the timeframe of this study. However, it does aim to shed light on some of the social inequalities that exist around gender, ethnicity and poverty when youths try to become digitally creative.

7.2.2 Data collection

Although interviews were semi-structured and tailored to each interview situation, there were specific topics that we covered across participants. Broad areas from the literature were noted and an initial interview schedule put together. The broad areas were built upon the literature review, covering: computational thinking, multimodality, affordances, educational pathways, software and creativity.

Interview questions aimed to help answer the research questions: *What are the affordances of 3D digital animation work for young people?* and *What possible connections are there between computational thinking and multimodality in the production of 3D digital animation?* And building on the results of study one, helping to answer: - *What characterises the opportunities for learning 3D animation in the formal curriculum?* Previous data analysis of the National Pupil Database (see above) have highlighted disparity in access to computing qualifications based on a range of socio-economic factors, including gender, school type, ethnicity and free school meals.

A pilot study of the interview was undertaken with 4 students attending the camp in 2017, this resulted in a more specific set of questions being put together and the decision to focus interviews entirely on the producers and directors at the camp. Interviews with students who were not taking up a management role in their teams resulted in a lack of data on multimodality and significantly narrowed the scope of the findings.

For the final interview schedule comprised of 28 open ended questions under the following headings: Student background, finding out about the cultural and social context of each student; Role within the film, what did the students do, how did they use computational thinking and how did they interact with each other; The film, how did they describe the film and their choices in making it; Learning pathways, how did they learn 3D animation, what affordances and constraints did 3D animation offer. The schedule is included in the Appendix

The above topics allowed me to explore the various discourses that students were using when making 3D animations. These discourses include their use of computational thinking and their application of multimodality. The results and discussion section below is built to look at how students are being digitally creative by using the systems model of creativity (Csikszentmihalyi, 2013). *Field* is explored through looking at the educational and social backgrounds of students based on capital (Bourdieu, 1986). *Domain* is explored by looking at computational thinking and multimodality. With computational thinking taken to be abstraction, algorithm, decomposition, pattern recognition, automation and evaluation (as argued above); and multimodality taken to mean discourse, design, production and distribution (Kress & Van Leeuwen, 2001).

Interviews averaged 45 minutes each, with several under 30 minutes and others over an hour. Interviews were either conducted in person on site at the camp, or after the event over Skype. Attempts to interview some of the directors and producers during the event proved fruitless as they were far too busy managing their teams to spare the time. As Skype calls were recorded, any interruptions to the call could be rectified by stopping the interview and continuing from where we left off. No interruptions were noted for all the interviews undertaken. All students were invited to sign opt in forms for the interview process, additionally parents of students under 18 were also asked to give their consent (see Appendix).

Additionally notes on the camp were recorded and access to the final films was provided on an online video platform. This allowed me to look in detail at the use of computational thinking and moving image literacy, beyond the self-reporting of interviews, as well as exemplifying some of the points brought across by the students (Punch, 2009, p. 153).

By using the above framework I am able to describe how students are digitally creative using 3D animation. The study of computational thinking and multimodality allows me to describe how the discourse of computational thinking interacts and influences the discourse of multimodality; in addition I outline how the heavily digital nature of 3D animation impacts student's use of film semiotics.

7.3 Data analysis

This section describes the methods used to manage, organise and analyse the interview data. All interviews were audio recorded using a voice recorder or over a software based Skype recorder. Audio files were stored on secure encrypted drive and transcribed verbatim using an online transcription service, with participants' personal details (e.g. name) anonymised. The names you see in the discussion below are pseudonyms to preserve interviewee anonymity (Cohen et al., 2012).

Interview transcripts were broadly coded making notes of emerging themes using the *NVivo 12* qualitative research software. To achieve this, I moved back and forth between transcripts updating the themes and categorising new sections of transcription in previously visited transcripts, as themes emerged across transcripts (Bogdan & Biklen, 2007). In the initial stages of this work I applied broad thematic categories across 3 transcripts, which I then provided to a colleague who independently coded the interviews. I checked my coding against hers and discussed any differences we had, until we came to an agreement. Our work was broadly comparable, with themes emerging around the computational thinking, media literacy, student background and diversity. Having such a procedure involving two coders is likely to enhance the trustworthiness of the qualitative work (Lincoln & Guba, 1985).

The approach to coding involved moving between higher and lower level concepts, with lower level concepts often preceding the recognition of the higher level concepts under which they sat (Corbin & Strauss, 2008). These lower level concepts included observations from multiple students about female interest increasing in more creative interpretations of computing, strong parental and family support for student 3D animation activities and a lack of support for 3D animation in school. As the coding process continued, further categories and themes emerged (Miles & Huberman, 1994) which were then incorporated into the structure of the coding. The whole process was highly iterative, moving backwards and forwards between theme levels, adjusting these hierarchies and description, sometimes recategorizing transcripts when better or more nuanced themes emerged (Corbin & Strauss, 2008; Spencer, Ritchie, & O'Connor, 2003). It should be noted that emerging themes were heavily influenced by the questions asked and the literature base on which I have built this thesis. Much like the argument above for a subjective approach to the interpretation of research, I recognise that the context in which I have been analysing these transcripts is highly influenced by the literature review section of this thesis. Whilst it appears pre-determined that I will be coding transcriptions to match, for example, computational thinking terminology, this is not necessarily a negative issue, as the iterative coding process described above allows for the development and refinement of themes (Hammersley & Atkinson, 2007). Overall my coding process is a combination of deductive and inductive approaches, with themes from my literature review being used to categorise transcriptions, and data from the analysis of transcripts being used to create new themes (Elo & Kyngäs, 2008).

Coded themes fit into four broad categories: socio-cultural capital, software and hardware, computational thinking and multimodality. With concepts related to these themes influencing some of the sub categories.

For example multimodality is broken down into Discourse, Design, Production and Distribution categories taken from Kress & Van Leeuwen (2001).

7.4 Ethics

This research was approved by the University of Roehampton's Ethics committee (EDU 16/ 110) in July 2016. Ethics approval was needed for study two because this data includes student personally identifiable data such as gender, ethnicity, poverty indicators in the form Pupil Premium, family structure etc.

My role in the camp was as a teacher as well as a researcher. This teaching role meant that I built a positive working relationship with all the students interviewed. I felt that this meant students were more likely to take part in the interview process and were more likely to offer truthful responses as they were speaking with someone that they had learnt to trust. But this might also be considered a problem, as students would be interviewed by someone in a position of authority in running the course.

To take part in the research, students and their parents were asked to opt in through the completion of signed research permission forms. These forms outlined the nature of the interviews as well as the opt out processes and the details of the PhD supervisor if they had any questions. For students eighteen or over, only the student signature was needed to opt into the research, other students required a student and a parent signature. Part of the interview schedule involved talking the students through the process of the interview, this included descriptions of how their responses would be anonymised and information on how they were free to opt out of the interview at any point (see appendix). Students were asked for their oral consent before the interview started.

All interviews were recorded on a voice recorder with recordings being stored on an encrypted disk drive. Interviews were transcribed verbatim using an online professional transcription service. Prior to submission of sound files to this company all names were deleted from the files. The names given below are all pseudonyms to protect the identity of students involved in the research. On completion of the thesis all files will be destroyed.

Students on the course were self selecting in the sense that they had applied for the course through choosing to complete a portfolio of their work. To attend 3Dcamp students had to complete parental consent forms and media release forms. The parental consent form allowed the students to take part in the course, the media release form allowed 3Dcamp to use their image and their work for any purpose, including the publication of the films online, where images for this thesis were taken from. The research permission forms discussed above were entirely optional and several students chose to opt out of this process, reasons for this were not pursued or recorded.

7.5 Results and discussion

I now present the results from student interviews organised by three categories covering research questions two and three, with an additional section on student views on creativity to allow me to question student self-understanding of the topic on which they are being evaluated. These categories allow for the presentation of data covering the research questions and a structure by which I can attempt "to understand the role of 3D animation in supporting the development of digital creativity". Under each category broad themes resulting from the *NVivo* analysis described above are presented. Sub levels of themes are not shown in all cases, with several lower concepts combined under single higher concepts for ease of presentation and clarity of argument. For example, relationships with parents and siblings are combined under *Family*. Throughout this chapter I apply concepts from the literature to interpret the data presented. With common connections made throughout to the systems model of creativity (Csikszentmihalyi, 2013). Coding took place against the following categories and their subcategories:

- Capital
  - Family
  - Peer support
  - Cultural inspiration
  - Education
  - Self-learning
  - Futures
  - Diversity and digital making
    - Ethnicity
    - Gender
    - Socio-economic
  - Software and hardware
- Computational thinking
  - Abstraction
  - Algorithm
  - Decomposition
  - Pattern Recognition / Generalisation
  - Automation

    - Evaluation
- Multimodality
    - Discourse
    - Design
    - Production
    - Distribution

7.5.1 What are the affordances of 3D digital animation work for young people?

This section builds on the noted inequalities in access to computing and media education outlined in study one. It explores the family, social and educational backgrounds of students attending the camp and their views on the restrictions people might face when attempting to become digitally creative with 3D animation. This section builds on Bourdieu's (1986) concept of capital, looking at *social capital* through the analysis of student's families, friends and education; *symbolic capital* through looking at students access to qualifications and competitions; and *economic capital* looking at financial and software and hardware issues that face students. By looking at these factors I can outline the affordances offered by 3D animation and how they are limited and supported by the social capital available to them.

7.5.1.1 Family Most students mentioned family members being involved in their paths to becoming 3D animators, linking in with Sefton-Green and Brown's (2014) research on mapping digital making pathways which highlighted the importance of family members amongst middle class students. Examples included Catherine's sisters helping her with digital making at home and Herbert's parents offering support for his interest in pursuing his hobby of 3D animation. There were no examples of family members being involved with 3D animation themselves, but many family members were involved with related areas such as sound editing and computer science.

Derrick's father was a sound engineer for the BBC and his mother had a computer science background. Where family didn't have a link to a directly related field, family members were supportive, Sazia: "So if they know I'm doing something they're like, 'Oh, well that's quite cool. Show us that when you're done' ". Most students had a strong background in 2D art, shifting this interest into the third dimension. Mike's father taught him how to draw: "I used to really like drawing, as a kid, and he'd teach me a few techniques on how to draw. None of which I remember now, but I guess it's sort of helped me with enjoying drawing because I could do it better than others". Charlie's family were supportive of his interests:

> I remember the day I came home and I told my mom about how I was really interested in

> animation, 3D animation, she was really happy and excited about it. It was the first time she heard me say something that I was interested in and wanting to pursue that wasn't video games or anything.

Two students had mothers who were computing teachers who recommended the camp to match their daughters' interests, Teresa: "She is on that computing at schools[35]. You're on it as well, and she found you and she told me about it.", Mari: "It was more sort of oh, that's cool, you can do that".

7.5.1.2 Peer support Within their schools, most of the students experienced little peer interest in 3D animation, Charlie: "I was very much on my own. There was no one else at my school really who was doing the same thing I was", and even though other students thought their interests were 'cool', they seldom joined in, but remained encouraging. Catherine's friends were very interested "to do something based off art, or going into animation, or gaming", but not interested in learning 3D art at this stage". Sazia attempted to position her and her friends interests within the wider picture: "A lot of my friends do acting and stuff, and so I've seen that side of it [...] but I still prefer the other side, the actual [computer] animated side and stuff".

There were several examples of students working within friendship groups to provide 3D animation for other people's projects, Charlie: "[I] actually did a visual effects in one of the films my friends are doing. My friends had their own interest in mind and we supported each other's goals that we had". Herbert was one of the few examples where another student actually did 3D work with him: "he and I worked together [...] he kind of came up with the idea for the first animation project we worked on. And I did most of kind of the actual animation work, he did some of the rigging and was mainly kind of responsible for the art side."

Mike thought that the difficulty of the software might be holding his friends back: "I guess it's a little bit more difficult to get into, but I think you have to have that dedication to do it, which I don't think many of my friends had the interest to do, so it was mainly just me". Mari also notes the difficulty, due to lack of support: "They would probably find it quite difficult because there's not much [support] around us which can help and there's not much for technical sort of push and new sort of skills". The free time needed to get good with 3D animation was also another potential barrier, Jake: "by the time that they [friends] were doing A-levels, it's not really the time that you want to be starting a new hobby because you're quite busy". Sazia's suggested that her [female] friends might not be interested in 3D animation as: "they don't really like technology", with Mari agreeing: "I don't know whether they [female friends] would be interested in this because quite a lot of them wouldn't be as interested in the technical side of it". This support studies around males being interested in more technical subjects than females (e.g. Wong & Kemp, 2018).

[35] Computing at School is a subject group for computing teachers in the UK

This lack of peer engagement was contrasted with attendance to 3Dcamp, Ono: "When I went to 3Dcamp, that was the first time where I found such a high concentration of people who think like that [in a similar way] though". Catherine mentioned that the people on 3Dcamp had similar interests to herself: "they seemed to like the same things, like anime and stuff".

Constructive 3D animation friendships are largely within the group of students attending 3Dcamp, with students working in their own time during the holidays to make further films, Jake:

> [I worked with a] community of people who have been to previous 3Dcamp sessions [...] first of all there [we created] *Hide and Sheep*, which I wasn't a part of because I was on holiday. Then there was Dr. Who, which I wasn't a part of because I've never seen Dr. Who and don't know anything about it. But then there was *Welcome to 2016*, and I thought, yeah, I could under this. So together it was C, H, M and me, all creating this film online.

Whilst an industry standard tool such as Blender is *expression complete*, offering the ability to make almost any artistic work, if students deem it too difficult to use then the affordance (McGrenere & Ho, 2000) of the software is close to zero. However, students are able to use the tool, as demonstrated by the films made on 3Dcamp, and the lack of affordance offered by 3D animation through Blender may be more a case of lack of education and time to dedicate to the tool than anything specific to Blender. With spare time being seen to be an important ingredient to being creative (Steers, 2013) the lack of time amongst school students to take up new programs such as Blender suggests that even if they did have interests in 3D animation, if school priorities did not dictate the use of 3D animation software, then there is little incentive to take it up.

7.5.1.3 Cultural inspiration Most students explained their journey into 3D animation as being inspired by seeing some form of media and wanting to make it themselves. These stories serve as examples of the democratising nature of technology (e.g. Manovich et al., 2001; Burn & Durran, 2007) putting the tools produced media into the hands of the consumer.

By engaging with Blender, Herbert was able to make something that he had seen on TV, he describes how he was very interested in Formula 1: "and the BBC had this cool animation at the beginning with these computer generated Formula 1 cars racing around. And I was thinking, 'Wow, I really wanna do this' ". . Burt turned a consumer passion into a hobby: "as soon as I'd watched animated films, something that I really enjoyed. I wanted to do something similar to that myself, I guess". Sazia was similar: "I used to like looking at films and looking at how they were portrayed and stuff. I was always like, 'I wanna do that. I wanna be an animator, a film-maker'. Minecraft featured as the inspiration for several students. Derrick: "I saw a Minecraft parody of a song, which had an animated music video like Sparkles and Jubbah. I saw a behind the scenes video of it and I thought, 'I want to do that.' ". Mike outlines how the game led him into using Blender:

> I discovered 3D animation through Minecraft animation. So really wanted to make these Minecraft animations when I was 11, and I looked up how to do it and I found Blender. And then I slowly developed that into an interest for making YouTube introductions for people [...] I think it was kind of what pushed me to do it, because I just wanted to make these things that other people were making, knowing that I could as well.

Blender is authentic, it is software used by industry. This allowed students to engage with the media that they consumed, with the affordances of the software allowing them to create the things they were interested in. However, usage is not without difficulty, with some students seeking the technical challenge, Derrick: "I was learning something a bit above what I should be and I enjoyed learning complicated things like that."

Several students started off with 2D animation then moved into 3D, Burt: "I did some 2D animations, studying different Japanese artists and stuff like that". Teresa: "I always took an interest in [2D] cartoons and I drew and I wrote comics. I generally really enjoyed narratives, anything with a narrative, especially visual drawings and animations, games, and cartoons, and so on".

7.5.1.4 Education Educational opportunities between students varied widely. Some, like Charlie, had a formal film education: "I studied high level film during my last two years of school. I felt I got a very good sense of timing. Just through literally, trial and error and seen what worked and what didn't". And as noted below, this paid dividends when working as a director. Most other students had no formal support within school, Teresa: "No. Nobody was helping me with this.", Derrick: "No, not [a formal education] at all. Like I was very on my own in it in a way". Herbert: "my school offered no other ways of doing it [3D animation] and none of the kind of mainstream local schools that I could have gone to offered it either". Sazia had high hopes for learning about animation in school, but was left disappointed: "going to secondary school and stuff, and nothing [media courses] being offered [...] You don't even have basic qualifications, how are you expecting to get into advanced ones?".

Several students mentioned that subject choice within the school was limited even when digital art related courses were on offer, Catherine: "You could do graphics, I wanted to do that, but then because there's this new thing called EBacc, so for universities you have to have one of the humanities, so I picked history". Sazia describes how she was made to pick between: "and then it was our four options, which was history, computer studies, ICT, and French". This matches the argument that the reforms in the national curriculum in England have reduced opportunities for students to study arts related subjects (Steers, 2014).

Within computing courses the digital artefacts that interested students were not always available: Catherine: “well, there was computer science, and coding, and making our own apps, but nothing on digital animation”.

The arts courses on offer also tended to be very light on the digital side, Derrick: “I was considering going on the art course but it was basically all drawing and you had to be really good at it and I just didn’t have that sort of … that sort of talent”. Sazia notes a lack of creativity: “You’re supposed to be able to express yourself, fair enough within a boundary. But in my school it’s like, ‘Do it this way or it’s wrong’. […] It kind of curbs your imagination. It curbs everything”. Sazia’s observation links to the idea that the assessment rubric can often drive the curriculum model, impacting room for creativity (Beghetto, 2010).

More worrying was the attitude that some teachers had towards Media studies, Teresa: “he said on several occasions if you don’t understand this go and take Media studies and he said it on two, three occasions and another occasion he said if you don’t understand this please take child development or something”. Whilst this is shocking and highly demotivating, study one supports the idea that Media studies students generally get higher grades than other subject areas which might help entrench ideas about Media studies being an ‘easy’ choice.

Only two students did 3D work as part of their studies, but without any assistance from their teachers, Jake: “everyone else did an advert about domestic abuse or depression or something, and I was like, I want to [3D] animate where some chilli sauce makes itself”. Charlie: “I focused on more of the computer side of art for all my assignments […] because we had a lot of freedom in those courses”. This freedom of choice in projects and outputs to focus on an area of interest, in this case 3D animation, matches the “scale and ambition” and “choice and agency” the creative pedagogy model from Thomson et al. (2012). Allowing Jake and Charlie ownership on these large projects gave them space to be creative in the medium they wanted, with excellent outputs and grades. This contrasts with Sazia’s teachers who limited her sense of agency, forcing the whole class to produce similar outputs, and the corresponding demotivation that correlated with this.

There were no examples of students taking part in face to face 3D animation clubs outside school. However, there were three examples of related clubs inside schools. The power of teachers in shaping the learning pathways of young digital makers echoes the results seen in Sefton-Green & Brown (2014). Jake: “the Film and Animation Club […] was established about five year ago. [But] That was just like plasticine [stop motion animation]”. Herbert: “So we did I think maybe two or three sessions with Blender. […] That was it, we were doing a simulation of dominoes”. Ono was part of a digital making club in school, but the teacher left leaving him lost as to what to do next: “I emailed her saying, ‘What else can I do to keep coding and keep doing what we were doing in that club?’ And she said, ‘Well, there’s various things including 3Dcamp’ ”.

Amy, Jake and Herbert all entered a national competition after being encouraged by their teachers. Herbert: "my computer teacher [...] introduced me to a 3D animation competition [...] he organised a minibus to take me up on the rewards day, and he also organised showing off the finished animation to the whole school". Amy:

> In secondary school, we did do some 2D Flash animation, but that was very brief and ... although when my teacher found out I could kind of do animation, that's when I entered the competition and ultimately found out about 3Dcamp

7.5.1.5 Self-learning Most student learning was self led using a range of online platforms. This matches the *digital creativity* of Sefton-Green (2013), where learning has been transformed by access to online environments, offering both access to learning materials and learning communities from all over the world. Examples included the YouTube website, Mari " I watched YouTube videos and learned from that". Catherine: "The Anime Crew [...] animate loads of things like the eyes, and they'd make mouth features [...] then I'd see how they did it [...] and I'd follow that.". Teresa was learning and being inspired by what she saw online:

> I think I first started browsing YouTube when I was about 10, 11. That's when I started discovering various other, not necessarily famous professionals, but other people, young maybe. Other people online who post their work independent artists and so on. I discovered their work and I read a lot of webcomics. It's all stuff sort of inspired me".

Sazia and Ono were quite dismissive about learning from sources other than the internet. Sazia: "I just teach myself". Ono: "there was no one ever in my life that I could ask to solve a problem because everyone else was interested in completely different things. So, online was where I looked really and I found whatever I needed". Mike supported this position, saying that the internet was the way for people to learn about using computers: "I think, if you're interested in learning, computing is something that's really easy to learn through [online tutorials] Computers are really, really accessible now". This supports Sefton-Green (2013) in arguing that digital creativity has a strong online and self learning component. Additionally, Teresa and Catherine ran their own online accounts to share their work with others.

Some students spoke about their use of more traditional forms of instruction, with Derrick talking about a book he used: "I bought his book on compositing and I basically did a different scene for every different effect that it suggested and that helped a lot". And whilst Ono mostly used the people around him to solve problems, he made reference to the 3Dcamp "Survival guide" (Haines, 2017), which was provided to all students.

7.5.1.6 Futures

Students could see the value of the course in it both mimicking industry and was useful for accessing the industry. The authenticity and meaningfulness of the event suggests that the event had the potential for being a strong learning environment suitable for creativity (Csikszentmihalyi, 2013). This Amy and Charlie were planning to study 3D animation at university with both of them suggesting that the camp had been instrumental in their choices. Charlie: "3Dcamp gives you that environment of what the industry is like. It gives you that collaboration and plus you're learning the technical stuff and I think that's why 3Dcamp was a big change … literally solidified my passion and my understanding of why what I want to do in my future". Derrick recognised that firms would be interested in his portfolio if he was looking for a job, not necessarily the qualifications that he might choose: "I will be able to build up my portfolio and have a very good quality portfolio to apply to jobs with and I guess have that sort of computer science degree as a way of saying, 'Yes, I'm quite technical and quite …' I guess intelligent I suppose".

Sazia outlined her subject choice algorithm, where she would pick whatever she appeared to excel at: "Basically, kind of depends on my GCSE results. If I get good in sciences then I wanna take these A Levels. But if I mess up-ish, then I wanna try … I'm gonna try and take media and stuff". This has worrying connotations for computer science students who are more likely, especially girls, to be doing badly at the subject, as shown in study one. Building on the idea that self-efficacy in a subject is a significant predictor of future subject choice (Schunk, 1991; Schunk & Pajares, 2002), it might also supports the hypothesis from study one that girls are better represented in A-level media studies than GCSE, potentially because girls have stronger relative grade profiles than boys in this subject.

7.5.1.7 Diversity and digital making

> When I think of computer science and the types of people in computer science, I think the image that most people have is a white male basically. When you think of animation, I don't have that same stereotype […] animation is combining the artistic and computing - Herbert

Students generally weren't keen to engage with stereotypes, Teresa: "My impression is, no I don't like stereotypes" and Ono: "I always feel a bit scared to talk about ethnic issues because I am a straight, white male". However, stereotypes about digital making (or knowledge of stereotypes) appeared to be present in most of the student discourse as well as there being differences in their own actions.

7.5.1.7.1 Ethnicity

The findings from study one about the uptake of computing related subjects amongst different ethnic groups highlight the over representation of Chinese students. Catherine: "to be honest, [Chinese students] are quite good with technology, and I guess maybe their parents push them a bit". Mike recognised the stereotyping of Asian people being good with technology: “that is a general stereotype that I hear quite a lot”. Charlie was keen to question this: “[someone says] ‘Oh, Asians are good at math’, I will say, ‘Well, some are and some aren’t. You just see the ones that are’, That’s just me and where I’ve grown up”. Sazia thought it was best seen as different expectations of parents, that might vary between cultures: “like the Chinese culture and stuff, they kind of … from when they’re little, they’re expected to aim high. Whereas, nowadays in this society and stuff, people don’t … even teachers have quite limited expectations”. Ono also thought that family influence was the key and that typical family interests varied between cultures: “ ‘Oh, well, you need to be the best’ From my experience of Asian families, that’s what they would prioritise”. Sazia also went on to explain that even though her school was very multicultural, there was a lack of black students and females in her school computer science class, matching results from study one.

Herbert speculated that certain cultures including cultures from Asia : “strongly emphasise […] rigour and maths and so on, are probably less likely to prioritise looser subjects like art”. Mari had a similar opinion: “they tend maybe stereotypically, they tend to be more the maths sort of science sort of thinking and less of more humanities”.

7.5.1.7.2 Gender Students saw gender differences in their own educational institutions and the temperaments of students. Whilst differences were noted in interests, no students attributed differences in ability to gender, against research showing female strengths generally lying outside STEM subjects (e.g. Stoet & Geary, 2018; Baron-Cohen, 2004).

The combination of art and computing was seen as a positive thing amongst students, who nearly all were of the opinion that mixing art and science would be more attractive to girls, Amy: “I think anything that’s more artistic generally tends to have a lot of females interested”. Visual effects and 3D animation were seen as being far more inclusive than the computer science industry: “it seems like VFX has a far better representation of girls […] I think because it’s a creative thing and for some reason it’s seen as more appropriate for girls to go into creative things […] a meeting point between male related subjects and female related subjects”. This supports literature on ‘creative’ computing being more attractive to females (e.g. Catterall, 2017; Wong & Kemp, 2018).

Within their schools, students saw the disparity in uptake of subjects among genders, Amy: “[media] because it’s more of an art subject, it’s, it is kind of dominated by females. As opposed to the stereotype of like coding and programming and computer science tends to be more male”. Mike: “in my graphics class, we’ve got a 50:50 split between boys and girls. And in computer science, we had one girl, who ended up not taking computer science in the second year”. Sazia: “only about 25 students out of the whole year group that decided to actually take it. Even then, five of us were girls. The rest of them were guys". This shows that students were well aware of the patterns seen in study one and other research on gender diversity in schools (e.g. Joint Council for Qualifications, 2018a, 2018b).

Charlie noted the gender makeup of the camp: "I know at 3Dcamp we had a bunch of girls on our team who were really good at the concept art [...] I think definitely girls would like doing the animation side instead of computing".

Thinking about careers Teresa hoped that being female wouldn't make it harder for her to take up a role in industry: "I'm hoping it doesn't matter. I know that men are more typically into technology and computers and so on". Herbert speculated that some roles might be more attractive for females: "I would say probably animation is quite likely to be more appealing, maybe, I don't know". And Ono was confident that people can do what they choose to do: " girls will still end up picking whatever jobs they want", adding:" 'Oh we need to change our brand scheme to appeal more to girls?'. Because the one thing that I really don't like and that my generation don't like in general is being told what to do."

Students generally believed that girls and boys would achieve what they wanted if they put their mind to it, Catherine: I think that everyone has equal potential, and I guess, if someone's interested in it more". However, Sazia, who is female, was less sanguine about her female chances in the industry: "It's like employers seem to think that guys are gonna do a better job in animating, and they're gonna do a better job in computing and programming than girls would. It's just the way it is", also linking male dominance to increased self-confidence: "[males are] like, 'Oh, yeah. I could do that.' I don't know where it comes from, but most girls, especially in this society nowadays are like, 'I wouldn't be able to do that. I'm sorry. I wouldn't be able to do that' ".

The above has outlined factors linked to gender and ethnicity. The focus now turns to factors around the cost of being involved with 3D animation.

7.5.1.7.3 Socio-economic

> I don't think you necessarily need a lot of money to be a good animator. It just gives you more tools, as any kind of artist choosing to work with colour or acrylic or colour whatever - Teresa

Whilst open source software such as Blender makes 3D animation accessible to students (Becta, 2005), it is clear that software isn't the only thing required for students to express themselves. Richer students were seen to have more opportunities to be involved with 3D animation, Catherine: "Most courses, you have to pay for to get in and it's quite expensive with all the technology, and if you have the technology it's a lot easier to do it. For example, if someone's from a poor background, they might not be able to afford what they need to get started". Amy elaborated on the costs involved:

> you need powerful computers to be able to use the kind of software that you use in the industry. As well as licences for programs. You'd also get other industry standard things like Photoshop [2D] and ZBrush [sculpting]. And then material designers things like that. Like the algorithmics substance series.

Mike also suggested that many students pirated software when they can't afford it, implying that students who don't have the funds might have to criminalise themselves to access digital art tools: "Obviously, I don't want to say, go and pirate it, but you technically don't have to [buy it], if you can't afford it".

Derrick also outlined the cost of hardware: "I think it's a lot easier to do if you've got a good computer. Like you can do it on bad computers but it does limit you in being able to look at what your render looks like and all of that". Charlie suggested: "you can't really do it on a cheap end laptop or anything"

Derrick and Jake mentioned that he had been spending money on tutorials to upskill themselves. Mike suggested that there was a hierarchy to tutorials, with the best ones costing money: "I think if you want the really, really good, amazing tutorials, they probably will cost a little bit".

Students made references to a range of social capital that they believed was related to the wealth of individuals (Bourdieu, 1986). Suggesting that students from richer backgrounds and with private school education would have better access to 3D animation through both access to technical facilities the support of knowledgeable adults. These factors will increase student access to the *domain* and the *field* (Csikszentmihalyi, 2013), through providing access to tools that allow students to express themselves fully, be it hardware or software, or advice on what to do next and funds to support them.

Derrick speculated that poorer people, and certain ethnic groups currently being more likely to be poor, would lead to a less diverse workforce due to geography and risk taking: "richer people are able to, like, consider going into a very competitive industry because like without having to worry so much [about working in less secure jobs]". Sazia speculated that parental encouragement was the main factor here: "A person from a richer background is more likely to have parents that have a better job than someone from a poorer background. Therefore, that parent has aspired and got that high".

Sazia thought that attending a private school might lead to a wider range of learning opportunities and more space for things such as 3D animation: "I feel like the [private school] teachers are more accommodating to your needs", but again speculated that this might be because of 'pushy' parents:"But then again, that might be because if not, the parents would probably sue them".

Amy's father worked in IT and supported her learning by buying her a specialist computer to support her 3D art creations: "my laptop was the cheapest gaming laptop you could buy at £500, so they weren't like super powerful, but I could run Photoshop and 3DS max at the same time and not have any trouble". Herbert had a similar story with Christmas and birthday presents being combined to: "buy RAM and buy better graphics cards and bigger hard drives and so on so I could work on animation". Catherine owes her family money for hers: "I got mine and it's quite expensive, so I still owe my dad". Jake used some inheritance money from a family member to pay for his computer: "I used about £1,200 of that to buy what I like to call my beast, which is just a really powerful computer with two GPUs in it and an i7. If I didn't have that, I would have failed media studies because it needed to be really powerful". In addition Herbert's parents supported his skills by funding out of school learning: "when I was considering it for a career position for instance they paid for some life drawing courses."

All of the above suggests that having money is an important factor for success in 3D animation. Where we are seeing the tools of the 'professionals' now being available for the 'audience' to use (e.g. Burn, 2016), this use might come with barriers to entry around the cost of hardware and software. I now cover these two elements.

7.5.1.8 Software and hardware All students had used a range of other software to create digital art before using Blender. The most common tools were Photoshop and the Scratch programming language. Students often found Blender when searching for how to create things online, with video tutorials often showcasing Blender over other products. Derrick: "So I just looked up animation packages. I think I tried one random one before Blender, which was really bad. And then I saw tutorials on Blender and it was actually really good. And then I got into Blender through that". This matches the findings in Table 3.3 that showed Blender having more tutorials listed on Google than other 3D animation tools, and helps dismiss the fear of Lakhan & Jhunjhunwala (2008) that Blender, being an open source tool, will lack support.

Many students gave the main reason that they were using Blender was because it was free, matching similar arguments for using other open source software (e.g. Lakhan & Jhunjhunwala, 2008; Becta, 2005). Mike: "it's free, for one, so it's really accessible". Amy also mentioned that Blender would run on older hardware meaning she could use it easily at home: "I don't think you need as much performance to run and it's free, so, that's a big plus". This matches my observations elsewhere that Blender is more likely to run on less powerful hardware (Kemp, 2016). Mike also mentioned the adaptability of code (Lakhan & Jhunjhunwala, 2008), but it was unclear whether he had ever made any changes to the software: "And because it's open source, people can start adding their own features to it".

Students that were paying for similar software or using free trials came across a variety of problems. Teresa: "I had a trial for the Adobe. I had a student licence for about a year and I relied on it quite a lot making flash and making motions and making everything look nice and smooth, then my licence expired and I couldn't find any other software". Burt mentioned how his school environment was great, but it was a different story when he and his friends wanted to continue making outside school, Burt: "[software was free], but just inside the school, but not outside the gates".

Whether students thought that Blender was holding them back or not compared to alternative software differed from student to student. Amy recognised the similarities between other 3D animation packages, saying that university staff had told her: "[you] can switch easily because it's [the different software products are] just so similar". Jake agreed: "it's all about getting the core knowledge down and knowing how a 3D package works", as did Mari: "the skills needed to use Blender would even make you skilled enough to be able to use most software". Using the above, I argue that the levels of *internal expression* available through Blender were seen to be similar to other software, however, students were concerned how Blender usage might be perceived by the industry, Mike: "[if you say] 'Oh I've never used Autodesk products, I've just used Blender products.' Then they might have a stereotype about you"' with Charlie offering his perspective: "[when visiting a company they had] five, six years of experience in Maya. No one really mentioned Blender. I reckon Blender is definitely the underdog in [industry]". Whilst the affordances of Blender might allow for similar artistic outputs to be produced, the brand identity of other software products was seen to offer greater affordances in terms of the impact of the art on other people.

Mike was unusual in being the only student to be making money out of Blender, something that would have been very difficult with an educational license of a different product: "I started making those [minecraft ident films] and selling those and I really developed my animation skills. And, I guess, kind of, fighting and choreographing fights". This was the only example of the *external expression* available through an open source product exceeding that of a commercial/student licenced version. Ono wasn't too worried with the licensing but did see another issue:

> Maya is free for an educational licence, Blender is free for an educational licence. [But] there's tonnes of hidden costs as well that you'll also need to render it, how are you planning to render it? You'll need a powerful PC. [...] So I'd say if you're willing to put in a bit of money or a bit of time then you won't, there's no limit to what you can do"

Herbert describes being able to run Blender on a very old computer: "my first animation [was on a] nine year old PC. And all the computers at my school were also probably about that age too. So it's possible to learn about animation and to produce animations of some probably reasonable quality without lots of money", qualifying this with: "if you want to work on the next Avatar or something, money does help". Whilst Amy acknowledged that Blender worked on weaker hardware than other products, she admitted that "you need powerful computers to be able to use the kind of tools that you use in the industry". Contrasts were made with the ease of programming in school which was seen as far less software and hardware intensive than 3D animation. Catherine: "Well you don't really need to buy much, like you can just download Python and get that [...] it's free and works on any computer".

The mixture of licensing issues, hardware restrictions and software limitations place restrictions on the affordances offered by 3D animation packages. Whilst Mike could make money from using Blender, a greater level of *external expression* than if he was using an educational license, he would still be restricted in the level of internal and external expression by the limitations of the hardware he was using and the limitations on outputs that this would impose; even when if he had picked an *expression complete* tool such as Blender.

7.5.1.9 Conclusion In response to the question: *What are the affordances of 3D digital animation work for young people?* 3D animation offered many students an opportunity to engage authentically with media that they consumed. In particular the affordances offered by Blender allowed students to recreate 3D animations that they saw on TV and in computer games, with media cultures that students were interacting with being a catalyst to learn how to make things themselves: "I wanna do that". By using an open source program, one student was able to sell his work, the affordance of the tool used allowing for *external expression*, that is commercial work, where other tools would have placed legal or financial restrictions on this.

Students didn't note limitations on what visual expressions were possible with Blender, but their expression with the tool was limited by other factors.

Family support was present amongst most students, where family members helped enable the young 3D animators through financial and moral support. Formal school support for 3D animation was lacking, but there were examples of extra-curricular clubs, teachers offering advice on next steps, and in a few cases students were able to take control of their own learning and produce 3D content for course work, albeit without the technical support of teachers. Both of these are clear examples of *social capital* (Bourdieu, 1986), where the knowledge and connections of those around them, helped students in getting better acquainted with the tools and skills needed for creating with 3D tools. Student peers were also supportive, but several students noted preconceived ideas about females being less keen on engaging with tech. Whilst the students at the camp were a mix of male and female, males were better represented.

Whilst no students were being taught 3D animation through formal settings, there were some examples of students getting awards for their out of curriculum work, and the verification of their unsupported 3D animation coursework can all be seen as forms of *symbolic capital*. Several students recognised the importance of collecting their work to present to potential employers through portfolios, and whilst they might not have had these complete, they were aware of the symbolic capital needed to access the industry.

3D animation software was seen as complex and difficult to learn. The students on the course largely taught themselves through online videos and online communities. Several students mentioned that the best learning videos were paid for and that hardware to be fully engaged with 3D animation was expensive, suggesting that digital creativity can be fostered through 3D animation, but,*economic capital* helps dictate the learning experience and temper the affordances of the software.

Now that I have addressed the second research question, I move on to looking at the components of knowledge and skills domain of 3D animation by addressing research question three.

7.5.2 What possible connections are there between computational thinking and multimodality in the production of 3D digital animation?

In this section I will outline how students used computational thinking and multimodality in their creation of 3D animations. It will attempt to synthesise both domains, showing how computational thinking and multimodality interact with each other. Finally, I argue for an expanded model by which we can assess the full range of factors that impact the student 3D film making process.

7.5.2.1 Computational thinking When questioned about computational thinking most students weren't familiar with the term, however they were familiar with the concepts within computational thinking. This section looks at student's reflections on how computational thinking was used in their film making, from a technical and artistic perspective. Evidence here supports the idea that computational thinking can be used in domains beyond the development of computer programs (Bundy, 2007; Wing, 2006) and that students can build automations without necessarily building algorithms. Whilst Jörg et al. (2014) suggests that animation can be used to engage children with computing, my aim here is to make the link clearer, how are students using computational thinking in creating animations?

7.5.2.1.1 Abstraction The most popular use of abstraction was the implementation of *information neglect* (Colburn & Shute, 2007), where digital makers "capture essential properties common to a set of objects while hiding irrelevant distinctions among them" (Wing, 2011). Students recognised multiple instances where they reduced the detail of the models they were making. From the outset Amy's team chose to make a stylised film, recognising that they lacked the time to fully represent the characters they were making "it's just like a representation of the original thing. It's just trying to mimic [reality] essentially" Most students mentioned issues with the speed of rendering[36], the process that outputs the frames that made the final film, and the need to use *information neglect* to speed things up. Jake describes the decisions made here: "in previous years a few of us have learned that if you try and go really high-poly then [...] you can't work with it because if one render doesn't work [because it's too slow], that's two hours of your life lost". Polygons are the basic building blocks of a 3D image and the more polygons you have [high-poly], the slower the computer might be in rendering the images. The rendering isn't the only issue here and the editing of models on student machines can also slow down considerably with more detailed models, Jake again: "if it's really high-poly, you try and move it and it'll take three seconds to do a really simple thing because it's trying to calculate where every single vertex needs to go." Representational choices are both artistic and technical decisions. Amy's team found that the background landscape was taking too long to render and as it was in the distance, the detail of the background could be reduced to just a flat image rather than a highly detailed landscape "it was originally 3D but then it ended up just being put onto a flat plane to [as] it was in the distance". The prioritising of processing time led to decisions that affected the understandability of the film, i.e. what was most important for the viewer, what was happening in the background or what was happening in the foreground. Jake also showed this sort of thinking when making the trees in the background of a scene "we went with a semi-low poly with the trees because there were kind of trees everywhere [...] we just did some blobs on sticks and it fitted quite well". Ono described how the use of glass in an array of buildings had slowed down the render "[we replaced] the glass with a static texture which barely anyone noticed, and that saved a lot of render time because you didn't have to render all the [reflections] flashing off the glass." Mike took another position on the use of detail, he used simple models for the crowd watching the start of the race that was taking place in his film, these models had far less detail than the runners of the race, the use of abstraction helped to outline the importance of the main protagonists: "You also have the [simple models of] people in the stands at the very start, but they're not super-important characters". This use of different levels of detail in the characters was also recognised by Jake: "we had too many characters to qualify for 3Dcamp approval [who recommend a maximum of three character], so we just went round it by saying we'll create a base character, we'll give them slightly different features like hair colour and different outfits to establish them as different characters." Other technical shortcuts allowed for the reduction in detail of characters, without much impact on the overall image being produced. Amy went on to describe how the

[36] https://docs.blender.org/manual/en/latest/render/introduction.html

number of polygons in an image was reduced through the use of a normal map: "[the crab] got a texture on it like a normal map that makes it look bumpy, but obviously it's just one flat plane [rather than lots of polygons]". A normal map[37] being an image that it attached to a flat polygon to tell the light how to reflect off it when it hits it, allowing for a flat surface to appear bumpy.

The management roles of the interviewees led to some conflicts with other team members around abstraction. Students sometimes made some very compute intense props that wouldn't work in the shots being made. Jake notes that another team member "designed a really beautiful high-poly corn grass, and we were going, 'Oh yeah, that's beautiful. Duplicate it 10 thousand times.' [it slowed down the render] so we just decimated it with about level four, and it still looked fine. Once we'd put it with the lighting and everything, still looked beautiful". Here decimation is the reduction in the number of polygons that make up an image.[38] Time also played a part in decisions with Mike encouraging simpler models so that the film could be completed on time: "I felt like keeping the models simple would allow us the time to actually make the film rather than having to spend hours and hours creating a huge complex model for not much gain". Whilst the choice of what to abstract in any given work can carry political value (Kress & Van Leeuwen, 2006), some decisions appear to have been largely practical and related to the limits of the hardware that was being used rather than imbued with meaning, i.e. model adjustment that caused no visual differences. The choice of information neglect by the students on the course took on several forms: the need to utilise the hardware, time restraints and message delivery.

Information hiding abstraction (Colburn & Shute, 2007), where detail is not lost, but accessible through interfaces created by the user, was also present in the development of the films. With several methods for doing this built into the Blender software itself. Layers[39] were used to handle highly complex models and scenes. Layers make use of the modular nature of models and sets, breaking them into different parts, each part being stored in a separate layer. You can then choose which layers to edit at which time, increasing the speed of your editing machine, without losing any detail from the final render, the other layers are simply hidden whilst you are editing. Jake describes another summer camp film where the film was split into layers holding the grass, the background, the characters and the house. Displaying all layers at once made editing impossible on the machines available, so the grass was hidden and a simple box put in as a proxy, hiding the grass information with a simpler representation. Editing of the other parts of the shot could then happen with this box telling the user where the grass would normally be. However, this use of abstraction whilst editing isn't always without its problems: "the computer can't really cope if everything's really high-poly

[37] https://docs.blender.org/manual/en/latest/render/blender_render/textures/properties/influence/bump_normal.html
[38] https://docs.blender.org/manual/en/dev/modeling/modifiers/generate/decimate.html
[39] https://docs.blender.org/manual/en/dev/editors/3dview/object/properties/relations/layers.html

and you need to keep moving everything to different layers [...] the grass was [too] high [...] because the proxy set was in the wrong location, so the grass was higher in the real set than it was in the proxy set". Another example of information hiding was the use of linking, where sets were constructed out of individual assets. This meant that one person didn't have to have an intimate knowledge of each component of a shot. Props and characters were being made elsewhere, all they had to do was to link the correct file using its name. This example of information hiding is described by Matt: "So the most important thing was that if we added something to the set we'd be able to change it at a later date if our requirements change. So we tried to use [...] linking as much as possible" Amy recognised the use of *information hiding* in the Blender interface itself, where buttons sat on top of complex computer algorithms, "I suppose Blender just having macro-processes within the software [accessed through] buttons and things like that [...]. They produce I guess they have a lot behind them. But the interface just makes it simple"

7.5.2.1.2 Algorithm Wing (2011) defines computational thinking as "the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent" (p.1). This representational form would normally be considered as an algorithm, generally expressed through computer programming. Whilst there was only very limited use of textual programming on the camp, algorithms were present in a lot of student work through the use of node editors, animations and instructions for other colleagues. Mike noted: "there's quite a bit you can do with programming in animation". The key components of algorithm design are sequence, selection, iteration and variables (Kemp, 2014b). I discuss how students used each of these elements in creating their own animations . *Iteration* is a key component of algorithm design, allowing the algorithm writer to specify when a task should be performed multiple times. Derrick noted the use of loops in his animation routines "we repeated a lot of [animation] cycles. So that walk cycle that Crabby [one of the main characters] did was repeated." The reuse of animation cycles allowed students to animate a character walking one step forward, by looping this, the effect of natural walking can be achieved. The time saving use of algorithms is apparent in Mike's response: "we thought instead of getting everyone to keep reanimating this run cycle, it would look less consistent, it would take longer, I just thought why not do a run cycle and then just move the character around? So we did that. So the run cycle was on a loop". After building the animation loop, characters could be set to follow a path, allowing for the runner look like they were running: "You could turn it off, if you wanted to do a bit of custom animation, but it was on a loop. You could just draw a sort of curve, a path, and the character would follow that around as they ran." *Sequence*, getting the computer to follow instructions one after another, was present in the animation work. Students used keyframes to tell objects where to be and how to act at different times, a keyframe being "a marker of time which stores the value of a property,"[40] such as x,y,z location, size, or rotation. Mari: "we had several team members making animation, sometimes they animated scenes that moved too fast and had to move the keyframes back or add and delete keyframes". Sequence was also used in the creation of textures, where images were fed into the node editor and had multiple modifiers applied to them in sequence. Derrick built multiple textures this way: "I used a lot of procedural textures actually [...] the ice I made using procedural textures".

Selection, an action taken dependent on some factor being true, was clearly visible in the development of textures and some of the animations. Derrick describes how he "used [selection] to make snow on top of mountains instead of painting it manually I used this script that made it [which turned the texture white when over a certain height]".

Jake used variables, values that can store values temporarily and change over time, to set random colours for trees and the outfits worn by members of a running race crowd: "It was just one person, and then when we added the material, we set a random number [variable] that would give them a different value [for the material colour] be able to be one and 255 [different colours]."

Ono noted that algorithms didn't always have to be written for the computer to process, supporting the idea that algorithms can also be for people (Wing, 2011). The instructions (algorithm) given to other team members were important in getting the film made "it was a case of that level of direction you're giving people not just tasks but you were giving them very specific instructions on how to perform those tasks".

7.5.2.1.3 Decomposition One of the first tasks on the summer camp is for the producer to break the film down into sets, characters, shots, props and animations. Breaking the bigger task of making a film into manageable components that can then be tackled separately (Barr & Stephenson, 2011). Amy describes this: "we only had two [sets], props could be reused across both sets, I imagine the clouds are reused. I think the sky textures, maybe. All the other assets were quite separate. Different people were assigned each task". The task allocation into separate tasks that are later brought together demonstrates the modular design (Bennett et al., 2013) of the films and is a result of the guidance given by the summer camp management and the needs of the students themselves. Mari helped allocate tasks to her team: "we broke down all the scenes into different, like, tasks, so different people would be working on different aspects. So like people would be working on like the textures and building the raft. There was someone working on the planks, some working on Pengy [the main character], someone working on Crabby and then someone else doing the set". Allocating tasks to match team member skillsets allowed students to focus on doing what they were

[40]https://docs.blender.org/manual/en/dev/animation/keyframes/introduction.html

good at. Creating characters is normally problematic, as a producer Jake put his best people on this: “they did a really good job on the characters, which just made everything else particularly smooth later on.”

To bring the decomposed parts of the film together, linking and appending[41] were used. Linking is where a pointer is made to an external file from within another file, any changes in the external file will be reflected in the linking file when it is reloaded. Appending is when a copy of an external file is made within another file, any changes to the external file after the append will not be reflected in the linking file. Linking was the most commonly used way to bring the assets together, Matt: “the most important thing was that if we added something to the set we’d be able to change it at a later date if our requirements change. So we tried [...] linking as much as possible”. Kress & Van Leeuwen (2001) state that designs might change during production, the use of linking allowed this to happen in a managed way, where assets could be swapped in and out, or updated, without having to change the assets that made up a shot. Linking supports a more ‘agile’ model of development, with the ability to accept change over following plans (Beck et al., 2001). However, linking was not without problems.

Whilst he appreciated the benefits of breaking the films into tasks that could be assigned to other people, Derrick describes some of the issues with appending and linking objects to sets and shots: “when you’re appending stuff [...] linking stuff, it doesn’t really name them [properly] and things get confused. It [Blender] was like not necessarily set up to deal with [poor naming] and things just went awry. He [another team member] wasn’t naming things [correctly].” Naming conventions became a big issue for Derrick: “I tried to make sure everyone named their files with some relation to what set they were supposed to be used in and then [...] the characters and then anything other assets would be named differently. I tried to make it like that and tried to make sure that people knew the rules”. Having a set of naming rules for computer programming is essential for maintainable and collaborative projects (Green, 2017) and naming conventions seen in programming also have a use in 3D animation.

Other issues around modular design had been faced by Herbert in a previous summer camp, with assets being made that were mismatched sizes, or wrongly named. From the outset he created all the assets and set up a fully linked shot with placeholder props, sometimes just grey cubes: “one of the things that I tried to do this year was produce a master shot at the beginning. So due to the way that Blender works with the linking, and linking characters into scenes, in order to ensure the right scale by creating a master shot, which we then saved over all the individual shots.” This linking together sets from the start with unfinished assets demonstrates that modular design can be built into a 3D animation project from the beginning, demonstrating that these Blender 3D animation projects are forms of software based multimedia projects

[41] https://docs.blender.org/manual/en/latest/data_system/linked_libraries.html

which lend themselves easily to modularisation (Manovich et al., 2001).

7.5.2.1.4 Pattern Recognition / Generalisation With the use of linking, props were reused across multiple sets and shots. Producers looked at the individual shots and recognised patterns between them which allowed the same prop to be used multiple times. This led to direct reuse of props, Mari: “with the palm trees, they were the same [prop], but different sizes”. Charlie’s group also reused props: “ If you look at the first shot of our film, it pans down to the city and the buildings and the trees are the exact same except they are just changed in the size or the shape[…] We did reuse a lot of props which definitely saved us a lot of time in the final edit”. Matt notes that to achieve the city look he had to create “four or five different versions [of the building with] different colours, which meant that if you wanted to make a change to like the general look I would have to make a change to all five of those [and the whole city would change]”. This also applied to some of the character development, Amy: ”the other penguins were all copies of Pengy’s mother” and Charlie, with a few more issues: ”We were trying to copy and paste the rig between all three of our characters, but when one rig moved, all the other characters [moved …] we had to halt the whole production on the characters for about a day”. This reuse of assets matches the computational thinking definition of generalisation by the NRC (2010), where the same abstraction can be used and combined with other abstractions to solve different problems, demonstrating that forms of computational thinking can be seen in 3D animation.

Only having one type of house or tree didn’t work for some of the teams and they had to build out their models from a base abstraction. This development of specifics from generalisation was present in props and in character design, Amy: “there are some rocks in the other scene, but they’re not exact copies they are a more developed version of the other [original rock]”. It should be noted that this form of pattern inheritance is permanent, if Amy made a change to her original rock, the change would not be reflected in the derived rocks. Jake spoke about another form of pattern inheritance that wasn’t permanent, he made a base character that appeared in multiple scenes, “we needed a crowd, and I asked Tom if he could teach me how to automate colours. So he just showed me how to use the randomizer that would give someone a different-colored shirt and skin colour within a range that I’d set. And that was fantastic, because it just meant that I could duplicate one person in every single scene where I needed a person and they’d look different”. This is a simple example of a general solution (Curzon et al., 2014) to the problem of creating random characters and it could have been taken further to randomise skin colour, hair colour etc.

Textures were also reused across multiple models, meaning if the original texture changed, then the change would be carried across all the models that used the texture, Amy again: ”we had some people texture painting and that would be reproduced onto a couple of different 3D models which other people would use". This yet again demonstrates the modular nature 3D animation, where tasks can be allocated to different people and solutions combined (Manovich et al., 2001).

Recognising patterns and differences allowed for short cuts in the development, but also allowed for artistic expression. Charlie talks about how his characters had different bodies, but actually shared the same arms and legs: "I remember I copied and pasted the arms and legs of both characters, but you can still see a clear difference between both of them that worked quite well. I think I would keep that if I did it again as it saved a lot of time". Ono noted how his team shared walk cycles, to make the pattern of the animation look similar in different shots: "animation libraries [...] were super useful because it meant that every character shared the correct walking animation in each shot [...] you could just drag and drop the animation library into your scene and you get the character walking in the correct way that the director had envisioned without having to reanimate the whole thing yourself"

7.5.2.1.5 Automation Automation is a when "[t]he power of our 'mental' tools is amplified by the power of our 'metal' tools" (Wing, 2008, p. 8). Automations can occur through programming and the creation of computational models; both of which, Wing argues, can apply to machines or to people. 3D animation makes use of several different forms of automation, some through programming written by the students and others through the use of inbuilt tools.

All teams used automation when rendering their shots, as they didn't need to render each frame individually, but sent off whole shots to the *render farm* that split the frames of the shot across multiple computers. Render farms[42] allow shots to be split into individual frames and each frame sent to a different computer for processing. Therefore a 24 frame shot, instead of being solely rendered on one machine and taking 48 minutes, could be split across 24 machines, each taking 2 minutes. The summer camp had a render farm of up to 1000 machines, but each team had to compete for use of the render farm and this led to problems, Amy: "I think our team just stole the render farm at one point, so, I don't think we had too many issues with rendering". Jake describes how his team were unable to secure as many computers on the render farm as they needed and had to resort to other tactics: "I was in there [another computer room] making sure everything was rendering locally [manually setting up each frame to render on each machine] because it was the only way that the Green Team couldn't steal our nodes [computers on the render farm], because if we sent a job and they sent a job, theirs would get priority and if there weren't enough machines". With the limited number of computers in the render farm team discussions on the length of time it took to render a

[42]https://wiki.blender.org/wiki/Source/Render/Cycles/Network_Render

single frame were very common. Jake again: “if you try and go really high-poly then it’s detrimental [...] you can’t work with it because if one render doesn’t work, that’s two hours of your life lost”. Matt describes how a choice of material increased render times beyond use: “I decided that it would be a good idea to have a glass shader on some of the buildings, and then we ended up arraying those at least a couple of hundred times. So that slowed down render times massively. And thankfully it was quite easy to fix because all the updates are done through the linking [so I only had to change one model]”. The lack of computing power was a concern for everyone, even though the computing power available on the summer camp was many times more than the students would have had at home.

As mentioned in the algorithm section above, students created a variety of algorithms to automate processes in their films, Derrick: “instead of painting it [the mountain] manually I used this script that made [the texture for me]”. Often the automations did half the job and then allowed for artistic interpretation on the side of the student, Jake created a system to automatically create trees, and once the trees were created he edited the result: “I could erase certain ones if I wanted to. So I got the brush after they’d all spawned and made sure that none of them were poking through farmhouses or on the track or any of that. So that was a massive time-saving advantage and you could make them all pick random directions, as well, so it wasn’t just one single tree facing exactly the same way doing exactly the same thing with the light. It was as if it was a real forest”. Instead of having to hand draw the ground, Mike created up a system that allowed him to automate part of the drawing process: “there was a material that we had set up that allowed you to mix two materials together, so you had a mud one and a grassy one and you could draw where you want the mud one, which was quite interesting, and we used that throughout so that we could get this kind of varied texture on anything [...] you’d draw black where you wanted grass, and white where you wanted mud and then it would sort of automatically mix that together.” More complex models could be built with the physics simulation, where instead of having to individually animate dozens of sheep, Mike treated them as particles attracted to a magnet and set them to collide with objects around them: “I wanted [the sheep] to go across the ground, without having to animate them all [...] So I thought simulating the sheep as, like, individual particles [...] it ended up looking okay, and they do kind of ramp off of the track and fly. But I mean that was just a problem that we had and couldn’t really get over”. Complex simulations like this take a lot of computer processing time and several techniques were used to get around the computational load. Jake: “once you’re happy with something and know that you’re not going to change it, you bake[43] it into keyframes, which means to take the individual positions of whatever the thing is in each of those frames and just assign it, so the next time you play it through, it won’t be re-simulating, it’ll just be playing back what it’s already simulated, which

[43] https://docs.blender.org/manual/en/latest/render/blender_render/bake.html

makes the process go much faster, and it means that nothing's going to change unexpectedly". Additionally Jake describes turning off another simulation when the camera was no longer looking at it "when it went out of camera view I just killed the simulation so it wouldn't slow down the render. Then once it worked, I just baked it to keyframes so that it would play nice and quickly". Array modifiers[44] are used to create multiple copies of a single object, for example a piece of fencing could be multiplied to create any length of fence. Charlie's team used an array modifier to quickly build a city: "definitely used [the array modifier] for a lot of the buildings and some of the houses we used. Just multiplied like a million houses". The use of array modifiers was seen as an important part of managing the workload for some of the team, offering shortcuts to making, but also the ability to better maintain the sets, as by changing the array modifier parameters you could quickly change the set, Matt again: "So the most important thing was that if we added something to the set we'd be able to change it at a later date if our requirements change. So we tried to use arrays and linking as much as possible"

Drivers[45] are another way of creating automations. Drivers allow animations to depend on the state of assets in a set. For example, Matt used it to create realistic wheel movements: "in this year's film the truck that comes along, the animation of the wheels is done automatically, so it's calculated based on the position of the truck", reasoning that "several different animators will have different methods for animating wheels, and it [drivers] just was an easy way to guarantee consistency across all of those [wheels]".

Other simulations were far more simple, leading Derrick to question whether they should even count as automations: "This year I think we had some camera shake [it's] just applying noise modifiers [to the rotation of the camera], instead of hand animating. But I don't necessarily think that applies under the definition of automation". The distinction between a tool and an automation was also something that Herbert questioned: "files with [...] procedural effects applied to them on top. I think in the majority of cases I wouldn't define that as the automation, because you still have some control as the artist over say the size of [...] the noise or how much of an impact that has on the image texture that you're loading. Whereas if I was to find some kind of automated texture I would consider that to be something that's created by machine from start to finish in some way. So there's kind of no human control if possible." The questions here are whether an automation needs to be the implementation of an algorithm, whether a model can be something other than an algorithm, and whether an automation can include human interaction. Wing (2011) argues that automations can take place in computers or in people, i.e. we can program people to do specific things. What we see above is a merging of both human and computer actions, where automations, once completed by a computer, are then refined by a person. This balance between using automations to complete tasks for

[44]https://docs.blender.org/manual/en/latest/modeling/modifiers/generate/array.html
[45]https://docs.blender.org/manual/en/latest/animation/drivers/introduction.html

you and doing it yourself is a fine one. As Charlie notes: “We had an automation at the beginning, but then I went back and literally, I put all houses down by hand.”

Ono recognised automation within the tasks that he as a producer set other team members: “Automation would be more setting up the tasks for the other humans to do. So, things like the asset manager we had was super useful because we could keep track of everything and just say,”Okay, look down the list of important stuff. This is what you need to do next.” Some of the above doesn’t neatly follow from an algorithm. And whilst Selby & Woollard (2013) argue that automation isn’t part of the computational thinking canon, it is clear that students are building computational automations without necessarily building programs/algorithms, that is they are thinking computationally, making a computer do work for them, without thinking algorithmically. If we take the definition of ISTE & CSTA (2011) “Automating solutions through algorithmic thinking (a series of ordered steps)” (p.13), then clearly much of what is happening above doesn’t fit that model (they do note that this is a minimal definition). But the students *are* automating tasks and as Manovich et al. (2001) notes technology allows the automation of “many operations involved in media creation, manipulation and access” (Manovich et al., 2001, p. 53). Using the evidence presented here, I argue that automation is an integral part of computational thinking in 3D animation, more so than algorithms, as automation was used in every project, often without writing computer programs.

7.5.2.1.6 Evaluation The roles of director and producer led to lots of conversations about how to improve work, especially when students had very different skill levels, Derrick: “He was definitely the least experienced on the team and whenever we tried to do animation, it just didn’t quite work. It was very, very blocky”. Evaluation took place whilst on a one to one basis whilst producers and directors were in the room and as a group activity as part of ‘dailies’, which could be conducted multiple times a day. Dailes focused on technical and artistic issues. With consistency being one of the main problems faced by directors, Charlie:

> I got my team up and we had a lot of breaks, talked about, in our group meetings, about what we’re going through, what was our challenges, and art styles obviously, was one of the challenges we talked a lot about to make sure everything was consistent, since you had three or four people working on the set. You got to make sure everything fits the world you’re trying to create.

Artistic decisions lay mostly with the directors and the overall look and feel of the film was shaped through the production of an animatic. The animatic was updated throughout the course of the camp, with the full film visible on day two albeit as a sequence of still frames from the storyboard. As the film closed in on completion the director (and often the producer) used the animatic to evaluate the progress of the film and where to prioritise work. Charlie: “so we sat around and made changes to the animatic to see what shots would work and how they express the story through film. It was mainly us who critiqued the animatic". This constant reference back to the initial idea of the film created on the first day links to L'Heureux et al's (2012) computational thinking definition where a maker constantly compares a computational artefact to the original goals.

For one team there appeared to be a hierarchy of issues subject to evaluation, once they got over the many technical issues, then they could start evaluating the artistic nature of the film, Derrick: "we breezed through [the technical setup] and we could focus a lot more on the art side, the artistic side and the animation and the way things looked."

This difference in skill level and the evaluation of work led to some producers picking certain roles for certain students to keep the film on track, Derrick: "I'd have to make up a random prop that we could just chuck in for people to make, especially him [...] it felt like we weren't really including him enough."

In addition to the evaluation of other people's work and the artistic style of their own work, the production of automations, as noted above, relied heavily on evaluating the feasibility of whether an automation could be built and executed in the time allocated. This links to the idea of efficiency as outlined by Wing (2006), where some computational automations might have to be abandoned if they wouldn't complete in the time available, or scaled back to fit within the limitations of the computational power available.

7.5.2.2 Multimodality The films are multimodal products, in that they use a range of modes to express meaning (Kress, 2009), with attempts to use film conventions to portray particular meanings (Bordwell & Thompson, 2010). For example, Ono's choice of a pastel colour scheme was deemed by him to make the film "light-hearted", building on his socially constructed idea of the use of colour. This part of the study now looks at the discourse, design, production and distribution model of multimodal discourse (Kress & Van Leeuwen, 2001), exploring how students engaged with these concepts whilst creating their films.

7.5.2.2.1 Discourse Several discourses were present in all the films produced. Firstly, several students were aware of the discourse involved in 3Dcamp, for young people making a film. That is they were aware of the limitations and expectations of producing a film in 3D animation, using Blender, in seven days, as part of an extracurricular camp, with a team of different ability peers. This background appeared to lead the students down similar lines of expression, Derrick, third time attendee: "I felt like it followed the structure of several of my previous films I've done at 3Dcamp because there seems to be the sort of very simple structure of [...] something bad happens and then they can work out of it". Mike's film had a similar narrative: "He's supposed to be a good runner but he's very unlucky, and he ends up in these kinds of situations, and ending up behind sheep, in mud, ending up through a chicken coop, but he keeps running". A discourse (Weedon, 1987) within the camp soon emerged, with shared knowledge of camp expectations and the range of outcomes that were possible within the constraints of the camp. Students were actively curtailing their expectations from the beginning with several speaking about the limitations they felt pressed upon them by the short nature of the camp, the students available and the hardware at their disposal.

Charlie referenced implicit expectations on what could be achieved due to the limitations of the camp helping to dictate the discourse he chose as a director:

> everyone tries to use a serious animation [or] a bit of a dramatic animation, but I knew that after some prior experience with 3Dcamp, I knew it took a little bit of time. It's very difficult to create an animation that serious because it always comes up funny because a lot of the time the animation is decent, but it isn't such good animation to show that emotion of the characters feeling like sorrow or feeling despair.

Jake told a similar story about decision making for his team: "[comedy] was probably better than the original concept would have been, because you'd have had to actually create an emotional connection with the audience. Well, I doubt any of us could have modelled a character [to convey that]". His recognition of team limitations curtailed his ambition, and influenced the film towards cruder forms of expression:

> if we had people who had been working in 3D for five years who all had degrees in filmmaking, would be able to make a brilliant sombre masterpiece on one minute. But we don't. We have 14 to 18-year-olds who have been using Blender for three weeks, all trying to create something in the space of one week [...] nothing's allowed to be subtle. It has to be really overt, and comedy is the best way to do that, and ridiculous comedy is an even better way of doing it. So it's: want a guy to have a really bad day? You don't make him fall over. You make him run through a chicken shed and get covered in feathers and eggs and then watch his fellow runners get shot.

Limitations in team skill sets also inspired the discourse of the film. One team did attempt an emotional film but with a hint of comedy, maybe for safety, Mari: "the sentimental aspect of the film kind of came across, Crabby was very sort of funny and his funny walk made sure that everything was all okay". Derrick described his choice of character type as being influenced by the skill set of his own team: "I deliberately emphasised that we shouldn't have people [character models] because they are so difficult to do". Ono also mentions the simplicity as part of the decision process for characters in his film:

> We tried to make the characters as much of an iconic design as possible, and they're quite easy to draw and animate. Which is another reason we chose the basic shapes that we did for the

> characters". This use of simple designs allowed for easier storytelling: "you can also build an entire city of boxes around him. We could make this one-upmanship even extend back into the background where there was the square gym and then there was the pyramid gym. So before you've even seen the characters move you already know the dynamic between the two.

Students were all engaging with creating cartoon like films. They were aware of the expectations and conventions present in these films, making use of what they thought to be a shared understanding with their audience, copying styles and techniques from the films that they themselves watched: Derrick: "I think mainly his eyes [conveyed emotion]; they show a lot of expression. A lot of personality in that way [...] the style of the eyes is quite unique in Pixar I think and like the whole sort of general sort of cartoony aspect of it" and "basically everyone wants to make sort of Pixar style film". Other inspiration came from the films *Happy Feet* and *Ice Age*, and inspiration for the characters was also closely linked to what they had seen elsewhere, Mari: "We based Crabby off [...] the crab in Moana". Mari also referenced inspiration from other films including *Finding Dori* and *Piper*, with her story being similar: "the sentimental sort of this happy, carefree, anyone really can look at it and sort of enjoy it because it's pretty to watch rather than being really childish or really old and deep". These multiple references to existing media products support Burn and Kress' (2018) observation that student films are heavily influenced by their own cultural experiences.

Inspiration came from other areas, including the natural world, Amy: "the mother; her design. Well they're based on a real penguin, of course. I think it's meant to be more like elegant; motherly. So there's definitely a contrast [with the baby] personality-wise", see figure 7.1. The use of the less realistic baby penguin allowed for more emotion to be conveyed by the model, it had bigger eyes, which could be animated, Mari: "we gave Pengy quite a bit of facial expression so that we could make her look sad and happy. And as well using the music, sort of setting the tone and having slow times and not so slow parts". The mother penguins eyes were much smaller and only drawn onto the model, the mouth was also not rigged for animation. The crab was also designed with nature in mind, but this time exaggerated, Derrick: "we deliberately made one claw bigger than the other [...] there's a kind of crab that does that and we thought that would be quite a good thing to do cartoonishly [...] Just to sort of have an identifying feature."

Figure 7.1: Different styles used to convey personality in penguins. Rigged and movable baby penguin face compared to static drawn mother penguin face.

Charlie used his own life experiences of a gym to influence his film: “I came up with the idea mainly because I go to the gym myself. I watched videos online of people joking about the whole gym-bro, and these gym-rats and they’re just in love with themselves and all they can do is look in the mirror and look at their muscles and everything.”

Meaning was conveyed through animation, Amy: “a caricature of a crab [...] he’s so lively, a lot of thought went into this animation, for his eyes as well. ’Cause he can’t move his mouth, but the amount of expression that comes from just a few simple eyebrow, eyeball movement was really impressive”. Emotion for Mike’s runner character was more difficult as his face hadn’t been rigged for animation: “when he gets scared, he jumps up first and, I guess, looks in that frightened pose, frozen, and then turns around and runs away because” and “When he’s waiting for the sheep to pass, he’s just standing there looking at his watch, you can sort of see that he might be a little bit annoyed”. Ono considered the actual character design to be largely irrelevant, claiming that it was the animation and setting that established the story: “The focus of the story is what they’re doing. I call this the grey blob test in that would the plot still work if every character was a gooey grey blob”, but also talks about the importance of eyebrows: “[they] express almost all of the emotion and we didn’t really tie them to the anatomy. So the eyebrows can fly off the characters heads when needed”.

Charlie’s film tried to keep the style simple: “[with lots of characters it’s] quite hard to follow because you’re beginning to think, ‘Who’s this character on the screen,’ where I wanted it to be super obvious which character is which and who is who. I was like, 'What if I made them completely different shapes and colours,' that ought to be pretty simple". But concerns were made about this choice: "my team said that it's very difficult to convey emotions without at least eyebrows or eyes because eyes hold a lot of emotion. We settled for eyebrows on all our characters to show confusion or anger." Complementing this with sound effects "of the giggles and grunts and everything to show how hard these guys are working. The girl laughing at herself for watching these guys try and win her over".

Mike's signalling of meaning was a little less subtle for his scary farmer: "We gave him a massive shotgun and we also made him twice the size of all of the other characters. I think that was actually an accident, but it ended up sort of helping the story because there's a really nice shot in there, from behind our character, looking up at the farmer, and the farmer just looks huge and really menacing and scary. It shows he's evil", see figure 7.2:

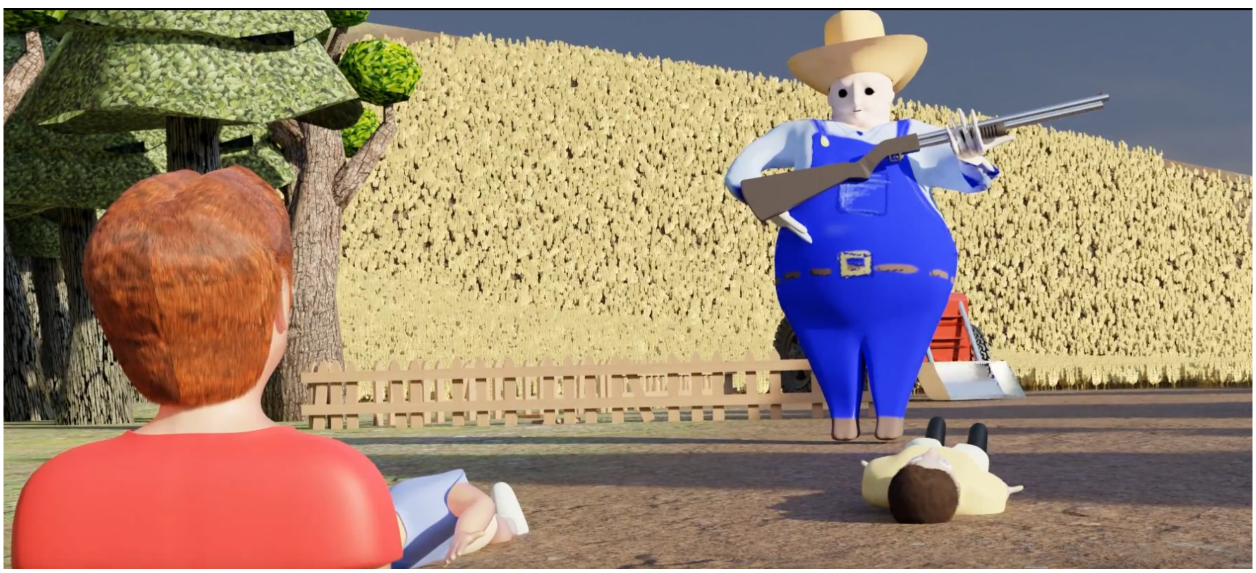

Figure 7.2: Scary farmer, use of height, shotgun and black eyes (and dead bodies) to convey the sense of evil

Discourses around gender were present with links to stereotypical, easily recognisable gendered tropes (Kress, 2009) such as female characters being pink, and male characters having big bushy eyebrows. Ono's team had masculine stereotypes trying to impress a female: "The city is divided into squares and pyramids. Both the square and the pyramid come out of gym. They find the attractive circle walking past, and they both try and impress her in more and more ludicrous ways. Eventually shoot themselves into space and neither of them get the girl". Herbert (see figure 7.3):

> [characters were defined by] massive muscles really. And also I think having the massive eyebrows

made it, I don't know, the whole machismo idea to these people was something that we really obviously focused on […] And then the woman who they're trying to attract […] she probably has pretty much no character actually. I think she can be whatever you want [her] to be

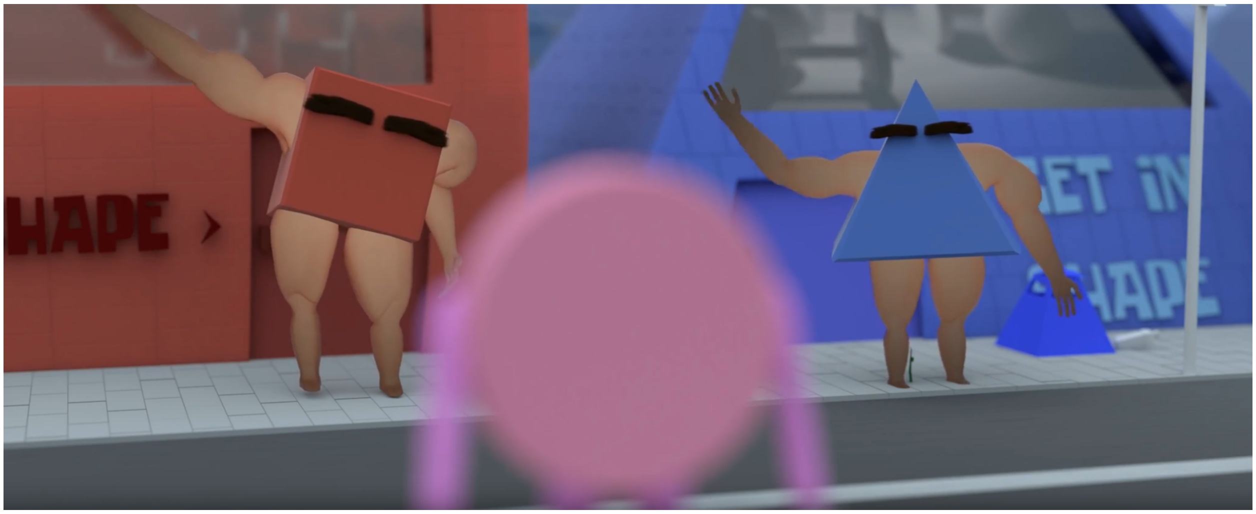

Figure 7.3: Use of shapes, colour and muscles to define different characters

There was also a recognition that the same film could be interpreted differently by different people. Charlie described his film as a comedy: "you take an idea and you just keep growing and keep developing that idea until it so ridiculously exaggerated that it's funny and you laugh", whilst Herbert thought the same film was "really getting across a moral argument" qualifying this with his recognition that: "the film itself doesn't take a particular stance on whether they are in the right or wrong or whether they're inherently good people or bad people or whether their actions are right or wrong. But I think depending on the viewer, you can interpret [it differently]". This links in with Peirce's idea of the *interpretant* (Atkin, 2013), different people will understand the meaning of the used modes in different ways, and Tarkovsky's (1989) "a book read by a thousand different people is a thousand different books." (p.177). Whilst students might assume that some signifiers would be easily understood, e.g. pink for females, other meanings might be harder to signify. As shown above, students making the *same* film had very different understandings of the messages being conveyed, suggesting, as Kress & Van Leeuwen (2001) notes, that "articulation and interpretation are not necessarily combined in one person in relation to a particular mode or set of modes" [p.41].

Modes from other film genres were recognisably brought into convey a story. Derrick used a sunset at the end of his film to convey a sense of hope and further adventure, see figure 7.4: "the whole going off into the sunset thing you get at the end of western films". Mike saw perseverance as a way of conveying goodness:

“ending up behind sheep, in mud, ending up [running] through a chicken coop, so obviously he’s reacting well, still keeping running, and not getting annoyed. So you could say he’s a good character rather than a bad character”.

Figure 7.4: Pingy and Crabby sailing into the sunset.

7.5.2.2.2 Design The discourses engaged by the students were brought to life by attempts to use well understood conventions of colour, camera and timing. Derrick’s film was an attempt to make something “quite wholesome [l]ike many Pixar films have a message of friendship as well and helping people who are struggling and all that [...] the textures I originally designed [were] to try and create quite bright and colourful”. Ono’s team used a pastel colour scheme in an attempt to make things light hearted. Amy recognised that their colour schemes weren’t entirely their own “You’ve got the colour scheme, I think primarily on the beach scene [...] It’s just a very Disney style I think”.

Different shot types were present in all the films, including the use of close ups, low angle, eye level, long, full, medium cut in and cut away shots (e.g. Bordwell & Thompson, 2010). The use of shot types also had an impact on the technical effort needed for a film, with Teresa developing the animation for a hip level shot and not needing to animate the bottom half of the character, or another character off screen because of the use of camera: “There isn’t another character, so he’s interacting with them off screen [I just animate] His top half. Everybody’s doing [animating] his top half.”

Charlie’s team showed the most advanced use of shot technique in their implementation of a *split screen* (Karasavvvidis, 2019) shot to show the emotion of two characters at the same time who were in different parts of the set, see figure 7.5. In addition this shot used several additional signifiers to let the viewer know that the square and triangle shapes were in love with the female circle, with a rose tint to the camera, and hearts floating around, clearly linking with the idea that hearts and a reddish tone convey a sense of falling in love. *Split screen* wasn't a filter readily available within the Blender toolset and had to be built using a node editor. This is a good example of how 'code' can be used to create new camera effects when they aren't already available, and an exemplar of how the conventions of film making can be joined with digital technologies, such as programming, to be digital creative (Sefton-Green, 2013).

Figure 7.5: A split screen shot used to signify that both characters were in love at the same time, use of love signifiers through added hearts, colour grading of film and use of eyebrows

This advanced use of camera might be down to Charlie's educational background which had introduced him to techniques such as the one described above and shown in figure 7.5. Ono noted that: "[Charlie] really had a good grasp on film and sort of the technical side of shot, reverse shot, tracking shot, pan, all those kind of stuff. [...] 'This would work because of this. This shot would work because of your funny reaction shot between both of them, the two guys' or whatever". Other teams struggled to articulate their use of camera in their films, even though different shot types were clearly used, suggesting they might understand the use of camera from their own consumption of media, but not be able to articulate what they are doing (Kress, 2009).

Timing was better understood amongst the participants, with its importance stressed by Ono: "Timing was probably the main source of comedy for the film" and noting that timing allowed for the development of comedy: "[comedy] was its main purpose and we tried to deliver almost all of that through placing of the camera and visual movement". Teresa described her film as "a bit absurd and a bit silly", partly because it was “fast paced I suppose that makes it funny”.

There were several examples of students implementing visual signifiers that they could clearly link to their own media consumption, supporting the observation of Burn & Kress (2018) that the design of films is partly drawn from a student’s own cultural experiences. Mike’s team used timing to create the effect of urgency in his film, when the main protagonist is wading through a pit of mud, cutting to the other runners, then back to the mud, then back to the runners and so on. The timing of each shot, mud or runners was repeated shortened until the character escapes the mud pit: “I timed it so that it sped up. So, the first one, you saw him wading a bit. You saw them running for a little bit. And then wading, and then running, and then it got faster until it went back to him catching up”. In addition other signifiers were used, the running animation was faster than wading, and the music for the runners more hectic than the gentler wading music. This technique was taken from Mike’s watching *SpongeBob SquarePants* when he was younger, but repurposed for his own use: “I think it was supposed to be a kind of argument between two people, but it would just really quickly switch between each of them, and it would get progressively faster as it got more intense. Which made it I guess more humorous and funny, and I thought that would be good to incorporate into our film”. Derrick’s team made use of montage which showed Pengy and Crabby making a raft together, this was also inspired by other media: “we had them constructing a raft in a montage. It’s also quite similar to Finding Nemo”.

Where timings of shots weren’t long enough, Charlie stretched them: “I wanted them to be a bit longer so she [the female circle] would have more time to react to the action [...] so I would have to copy and paste the last frames and stretch the last frame out for a second or so”.

Besides camera timings, timings within animations were important. Teresa noted that “Good movement and making things believable” were the most important things in “getting the message across”. She also noted: “[y]ou have to know how to exaggerate things sometimes” and referenced “the 12 principles of animation” a reflection of her knowledge of Thomas, Johnston, & Thomas (1995) from a course she had taken. Derrick’s story involved Crabby being surprised, shown in figure 7.6, they had him “hover in the air for a second or so” for comedy value and animated to character to “moves sharply [...] lots of personality there”.

Figure 7.6: Crabby hovering with legs flailing and with raised eyebrows to show surprise

Designs began on the first day with students creating the story, storyboard, concept art and animatic (a timed outline of the whole film which starts off as the storyboard and is slowly replaced with completed film, see *A 3D animation summer camp* above). The use of these initial designs varied between teams. Jake noted that his team "actually kept pretty religiously to the animatic that we planned out at the beginning", whilst Charlie noted that the design changed throughout the production stage of the course: "we drew out a lot of the art styles in the beginning and got a lot of feedback on that and evolved it into this geometric world [...] They went back and made another draught of the characters and the sets and the props and everything. They came back and it was a back-and-forth that we had for a while". Whilst he was the team's director, the actual artistic style was heavily influenced by his team: "I tried to bleach out the set. It was mainly a focus on the characters and I focus a lot more on conveying the characters emotion with animation and sound effects. I think my team wanted to have a bit more colourful set and beautified [it] a bit more".

Getting designs done correctly was seen as important to making the film believable within it's genre, Mike: "the set designs are done quite well because we had a lot of props to fill up the sets with, that were well-designed, and they brought the film together, it was believable, this is a farm, this is a forest". Charlie, again, described the more collegiate design of his film: "Our main challenge of the film was getting this set and the colours correct. I had my own vision of what the set would look like. It was then taken further and developed by the rest of my team". Teresa described her referencing of traditional media texts as well as real life in her designs for characters and animations: "drawing and live drawing is very important, and observation, knowing how people move. Looking at people, how they move, and so on. Analysing good examples, classic examples of animation".

Time allocation for designing the different elements of the film was an issue for Derrick, with a focus on his team's time on the major characters: "well, Pingy and Crabby were definitely artistic The mother penguin we just threw together because we just needed a mother penguin and we didn't really [...] focus on the creative side of it". Charlie noted the initial challenge for his team was: "getting this set and the colours correct. I had my own vision of what the set would look like. It was then taken further and developed by the rest of my team". Struggling throughout the process to maintain consistency:"we talked a lot about [in these meetings] to make sure everything was consistent, since you had three or four people working on the set. You got to make sure everything fits the world you're trying to create".

Designs weren't entirely fixed, nor were they always 2D drawings, Ono's team allowed modellers to interpret designs given a template: "Catherine had this concept art [...] So I just took that and tried to build it into 3D and gave that out to templates for others to work from". These 3D templates: "were files where you could just take our squash boxes or pyramids and [adapt them to] make them into a building". This is both an argument for the design process not necessarily leading to the finished product with room for interpretation being allowed, and the design process sometimes blending into the final product, i.e. the design becomes the final product (Kress & Van Leeuwen, 2001).

Student knowledge of the technology they were using heavily influenced their designs. Jake describes the decisions made here: "in previous years a few of us have learned that if you try and go really high-poly then [...] you can't work with it because if one render doesn't work [because it's too slow], that's two hours of your life lost", as a result the design of the film was for simple models. Mike's design for a simple crowd at the beginning of his film served two purposes, firstly their simplicity helped to highlight the more complex main characters, through the difference in detail, and secondly, the design of these characters meant that technologically the film would be achievable: "You also have the [simple models of] people in the stands at the very start, but they're not super-important characters".

This links with the observations of Burn & Kress (2018) that student choices of signifiers are influenced by the "the material assets provided by the technology" (p.7), faster computers would have allowed for more complex things to be designed. But it also shows the power of the discourse of the summer camp on the design process. Jake had a preconceived understanding about what worked and was expected on the camp and what didn't; a longer camp, with more skilled students would have allowed Jake to set his design expectations differently. You could argue that the discourse of the summer camp fits into "the cultural experience of the children" (ibid. p7), another factor that Burn & Kress (2018) argue influences design, but I believe that this definition needs expanding. The output of student based work is partially a function of the expectations and power relations present in the course or educational endeavour which the students are undertaking, not just their previous cultural experiences brought to bear on the task at hand. Where a group of students have been asked to make action movies, they will base their work on cultural experiences linked to action movies. But it is more than this. Where there are restrictions in place involving time and available expertise, as well as implicit and explicit course expectations, then, if students are aware of these limitations, they will adjust the outcomes to match what is expected by the course, *and* what they believe to be possible to make on the course. Student choice of signifier is linked to the *discourse of the course* they are undertaking.

However, the discourse of the course is not fixed, and Jake described an attempt to circumvent the restrictions of the camp by using the technology provided: "we had too many characters to qualify for 3Dcamp approval [who recommend a maximum of three character], so we just went round it by saying we'll create a base character, we'll give them slightly different features like hair colour and different outfits to establish them as different characters.", see figure 7.7, showing how new possibilities can be opened up when knowing how to use technology (Manovich, 2013).

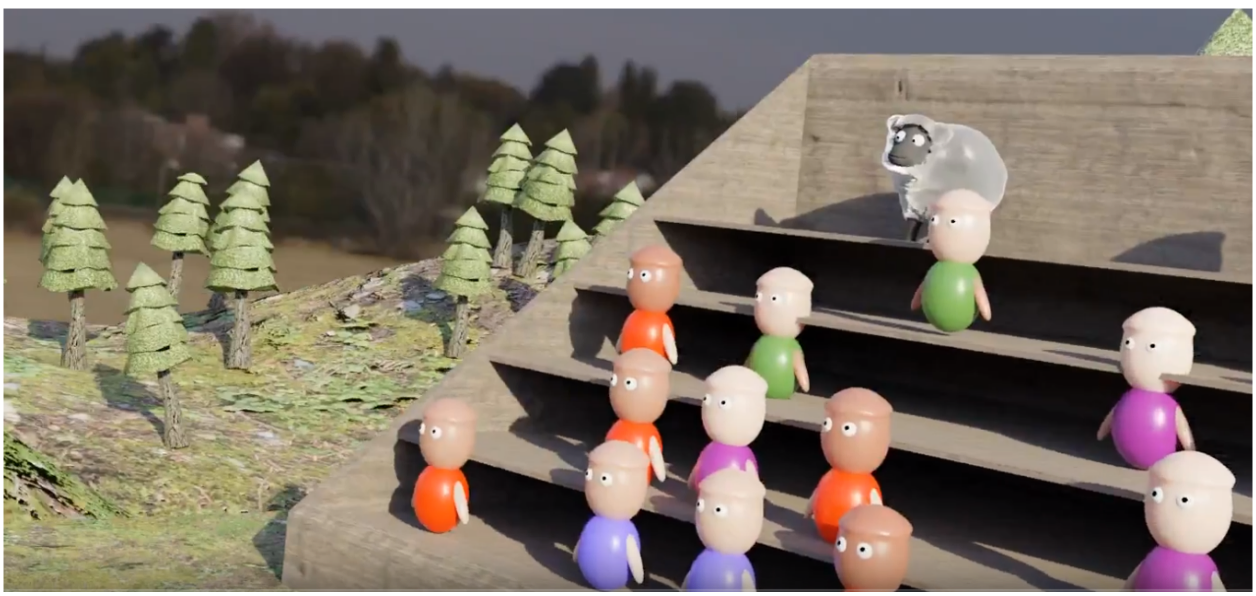

Figure 7.7: Simple characters, designed for artistic and technical reasons

7.5.2.2.3 Production No plan survives contact with the enemy and much of the design work put together by the teams changed once they started to make their films. Examples included Derrick's plan to use a blizzard to cut from one shot to another: "we were going to try to do a blizzard but I didn't have time and like just having Pingy walk away and the mother disappearing". Teresa was involved with animated several shots, and describes the details she had to be given to produce them: "As I'm making the shots I have to know how long it is. I was confirming with everybody else, how far away is the camera, how much are we going to see of the character?". This level of detail wasn't always present and often students had to go back and check with the directors for information on what they should do next.

The hurried nature of the camp meant that Mike regretted not spending more time "on actually getting the sets together, where everything's going to happen". Charlie also worried about his team's set, and the skillset of his team: "It was thrown together quickly by people who were still learning Blender and some of the models and everything had issues. I remember near the end before the film was rendered again, I went in and spent about a couple of hours touching up and fixing the set".

The management of other team members was the main role of the directors and producers. The asset management system was key to this, Jake: "It was my role to take control of the asset manager, to assign jobs to people", but all the students stressed the importance of one to one communication, Charlie, "I got up and walked around and gave feedback while people were working on it so they wouldn't create something and have to go back and change it all if it didn't fit".

Directors and producers attempted to learn the skillsets of students within their teams and assign them suitable tasks, Derrick: "I feel like it's sort of sheep wrangler kind of thing. You're basically just getting all the people of all the different talents to do the things that they're good at on time, which is quite difficult. Derrick and Ono considered this allocation of work to be the hardest part of their role, Ono: "The [biggest] problem was the utilisation problem [...] where the high expertise and high experience animators and modellers had so much to do while everyone else had quite little so we're really just stuck on improving stupid things like, 'Oh, this roof is slightly off. Can you go in and change that please?' ". Some students did drift, but the dailes and individual conversations with producers and directors generally kept them on task, Amy: "a couple people [were] just a little bit quiet, a little bit maybe shy or weren't too sure what they were doing, but usually that would be just sorted out within a meeting and people were back on track".

The unbalanced nature of the skillsets means that some students did more work than others, Mari: "there was a couple of people doing an awful lot cause that's mainly because they were the most skilled". When students were given tasks that they didn't know enough about they didn't always go to plan, Sazia, "I never animated before, so it went horribly wrong". The dominance of a few skilled students on each team led to some conflict, Jake: "a few people tended to get a bit annoyed at me when I'd [...] pass jobs to others so that they could be improved. I think they might have taken it a bit personally, but from that I just thought well, that's pretty much the way it is in industry [...] So I didn't they get hung up on it". Sometimes students worked very hard to find their work didn't make the final film, Ono: "X who was extremely talented and most of the time he just spent … he made a shopping centre that didn't make it into the final cut".

Some of the producers took an active role in upskilling other students, Herbert: "I was working with people who were less experienced […] balancing the time taken to try and help them and develop their skills, versus the time it would take to just give it someone who's probably very overworked but would get it done a lot quicker, is very hard for me".

Communication between team members was generally good, Amy: "I didn't see anyone who was just on their own. Everyone was kind of helping each other out. We had a very interactive producer and director". But issues did arise, Mari got a little upset with her team not following her instructions: "I was a little bit harsh. I kind of shouted at a few of them [and it worked]". Whilst dailies worked for most teams, Jake's team struggled with group communication, but were better with one to one:

> Everything's going to be fine. You're doing well. It's four days left". And everyone would just stand around going, "Um …" […] I went and talked to someone on with one-to-one basis and just went around everyone asking their opinions, because I would try pretty much every day to make people say things in dailies, and they generally wouldn't.

And a lack of clarity in instructions led to undesired outcomes, Jake again: "I think I just said, 'Can you make a basic feather?' So that was probably my failure in communication there". The feather produced was overly complex and had to be remodeled twice, by different people. It wasn't that the original feather was a badly modeled feather, but that the output was too complex for the computational model that was being used. Here decisions weren't just made on the artistic value of the item, but also their computational value. Whilst the original artist might well have had a shared understanding of what makes a feather feather like, they were not thinking enough about the technical limitations that the course placed on what they could make (Burn & Kress, 2018). Whilst the affordances of using Blender opened up a range of outcomes including the creation of a highly complex feather model, the constraints of other parts of the pipeline made these initial affordances redundant. It is not just the affordances of individual production software need to be considered with regards to the potential outcomes of a summer camp like 3Dcamp (Sefton-Green, 2005), but the combined affordances resulting from the complex interaction between software, hardware and the camp discourse of expectations, student capabilities and time available.

All teams had issues with the finite computing resource available to render the films, Charlie: "rendering takes just a long time. Rendering is a long process and you always have to find time for that". Amy's team found that the mountains in the landscape were taking too long to render as it was too detailed, changing the design to match the limitations of the computer system: "it was originally 3D but then it ended up just being put onto a flat plane to [as] it was in the distance", see figure 7.8. Ono had to tweak the glass in buildings to bring down the render time: " replacing the glass with a static texture which barely anyone noticed, and that saved a lot of render time because you didn't have to render all the flashing off the glass and glass is a notorious source of fireflies". Even when shots were set up to render quickly the finite shared computer resource was not always seen to be shared fairly between the team, Charlie: "[another team] took 80% of the render from the end because they were just so far behind and that really affected us. I've only tried to render one scene of 30 frames it was taking us two hours to do, but it should've only taken five minutes".

Figure 7.8: Flat background image of mountains that was originally made from polygons

The use of industry standard 3D animation software and the affordances (Hammond, 2010; Sefton-Green, 2005) that it provided allowed students to create effects that they were very proud of, Amy: "you've got really complex things like ice breaking and water and sunlight [...] Just as a whole it's just a really nice ... just really beautiful". Affordances here surpassed what students might have been used to their previous experiences with animation. Catherine described how keyframing in Blender compared to her previous use of stop frame animation where every frame would have to be individually animated: "3D art's a bit easier because you can just move one to another place and it'll figure out the middle". No students noted limitations of the software, but limitations of time, skill and overall computing power in restricting what they could produce.

Whilst the linking system (as described in *Mapping 3D digital animation to computational thinking*) and the software allowed for films to be built in a modular way, i.e. you could change any part at any time, Herbert suggested there was a hierarchy to the elements of the film that could be edited into the final artefact: “So like rigging, everything has to be done modeling-wise before the rigging is that done, whereas lighting, you can pretty much change throughout the animation, due to the way Blender handles those kinds of things”. Burn (2013) describes the design process involving the “the design of the contributory modes (character, set, music, speech) preced[ing] the design of the orchestrating modes [e.g. camera work]” [p.21]. This didn’t appear to be the case for Herbert, with a more fluid interaction with the components of the film possible throughout the filmmaking process. Models which didn’t require rigging could be changed/added/deleted at any time. The affordances of the linking process and the software available meant that most components could be edited, even when they were already placed into a final shot, offering a deep level of remixability through the software stack (Manovich, 2013). The fixity of the 3D animation process came about with the act of ‘rendering’, beyond which the components of the film were unable to be moved.

Students soon found that they needed to start prioritising tasks to make sure that the film was made in time. Ono saw his team working more on the characters than the sets and his team cut entire shots that they didn’t have time for: “There were lots and lots of shots that we decided we didn’t need [...] we just picked all the ones we could do [in the time]”.

The final film was put together by each team’s director, building up from the original animatic; Mari describes the process involved: “[it] started off with pictures of our storyboards and as we got more and more shots done in the non-rendered version I would add them in and I was looking for music and sound effects to go along with it and working out roughly what lens I wanted everything in and how it all sorted together”

The end of production often involved a lot of waiting on the render farm to return the completed shots. Sometimes entire shots were dropped when there wasn’t enough time left, Mike: “it was just mainly time limitations. It would have taken too long to render by the time that it was finished, so it was easier to leave it out than try and put it in”, or left in a rendered, but not polished state, Ono: “we had to prioritise which shots were the worst, that we needed to fix in the end”. Jake appeared shocked when everything worked: “I was sat there with Mike and we were both watching something render with our heads in our arms, just saying, ‘This isn’t going to work’. And [...] we managed to pull it off!”

No team was fully happy with their final film, with Derrick missing his blizzard, Mike his realistic mud simulation (see figure 7.9) and Charlie:

> my vision was to have maybe another shot of the girl and all the evidence of all the two guys ever existing were just removed from the whole film and then the girl’s just standing there alone. [...] but I don’t think the timing quite worked. I would definitely go back and change that up and see

if I could do it better. Maybe when they bounced the trampolines bounced away or something like that so it all happens at one moment and then they all … it disappears. The two guys and all the evidence of them ever existing in the film just disappears in one go.

Figure 7.9: Missing mud simulation, runner wading through the *ground*

Evaluating their films, everyone had something that they would like to improve. Mari looked at her leadership: "I would probably try and work on being nicer and sort of like distributed tasks better and made sure that everyone knew that they were doing everything. That I wasn't so like uptight about how everything has to be perfect. I'd be less of a perfectionist". Derrick thought that maybe he had focused on the wrong priorities for his team:

> reducing the number of props isn't necessarily the best thing to do. It's about reducing the complexity of the animation […] making props is relatively easy and you can reduce or increase the amount of them quite easily whereas the animation itself, that's the bit we had the most problems with [I tried to train them] but none of them really learned quickly enough and sort of ended up really not doing anything and I felt rather guilty.

Ono wasn't happy with the artistic style his team achieved, considering the final product far too dull and the use of light an afterthought: "the blues all meshed together into one building and the sky is a dull grey. I think it's a very vibrant film. The more that we can push out every inch of colour and emotion the more it would make sense […] there's no great lighting prowess on it". Charlie picked up on issues with individual shots: "the one where they're flying off into space, the two characters. There's a shadow cast across the earth which actually, somehow made it into the final edit from the space station", with Ono adding that this shot might even have been finished, but left out of the final cut: "I'm 90% sure we re-rendered that earth shadow. I'm very upset about that". See figure 7.10.

Figure 7.10: Shadow of satellite on the Earth's surface betraying the real scale of the models

Mari felt that she would have benefited from improving her skills before attending: "beforehand I would brush up on a lot more skills because I thought I went into it not knowing that much about lenses, sort of knowing enough skills to do what I did". Ono was keen to work on the sounds, something that is always an afterthought on the course (Haines, 2017): "I would take more time, syncing up the sounds". Derrick was keen to get his team naming their props correctly so they would link better with each other: "emphasis[e] how important naming things is or maybe having one person like maybe a producer who does go through at the end of the day and renames everything". Mike thought his team could have used fewer, but more polished sets: "I think we'd try and simplify the idea because [...] we didn't need three or four sets". Jake, in his third year on the course, was a bit more resigned: "there's going to be issues, as there are every year, with rendering, files getting deleted, files getting overwritten. All sorts of havoc".

7.5.2.2.4 Distribution All the films were showcased at a premiere in front of student's friends and families and industry workers. After this the films were uploaded to a video sharing website. Students had different ideas about the audiences the films were made for, Catherine thought: "everyone [...] and maybe my friends, and any family, then I suppose other people that are looking into 3D" . Charlie thought their gym film would be suitable for people who could relate to the muscled 'gym bro': "Mainly it would be funny to or be quite funny to fitness people or other people who have witnessed this, I think can be related to a lot of people. People who were very into fitness and they see how these bros, these guys who they are so in love with themselves". Herbert, on the same team, saw a broader appeal:

> I think [the film appeals to] anyone who has been in a similar situation, not necessarily trying to show off how strong they are to someone that they want to impress, but anyone who's looked back at some actions that they've done and thought it's completely ridiculous what I was doing to try and impress this personal or to try and show off my skills in some way. So probably most people, I would say.

Ono, also being on the same team, touches on what he believes to be an expectation of all 3Dcamp films: "3Dcamp films are all ages but … there's nothing that could not appeal to adults or children and so for that reason alone I'd say it's for everyone". It should be noted that this isn't part of any official guidance given about the expectations of 3Dcamp (Haines, 2017), and forms a component of the *camp discourse* available to the students.

There was a fear amongst two of the teams that their films would be remembered for technical aspects rather than the story and artistic feel, with these being felt to be the most important aspects in their films. Charlie: "I know some of the other teams had a lot of technical issues, but we breezed through and we could focus a lot more on the art side, the artistic side and the animation and the way things looked". Derrick thought his film would be successful when the audience would say: "it was like a nice story rather than it's really well … that's a well done animation". The technical aspect had to be done well enough to be invisible to the viewer, the focus being on the film signifiers and the intended meanings.

On first observation, films appeared to be made for the people who were making them without much thought of an external audience, an external audience being one of the key components of media education (e.g. Buckingham, 2003). Jake: "We created it … like, we all enjoyed it, so I guess we are the primary audience". However, you could interpret this as meaning the audience were the people who made the product, Herbert removes an external audience entirely from the end goal, but at the same time suggesting that : "I think it probably ended up just being a film that we would laugh at ourselves, when we were making it". A lack of external audience might have created a situation more suited for creativity, by removing a more formal type of assessment, that of students judging the success of the film against the approval of a particular audience group. A lack of external audience might have allowed students to be more engaged with the process of creation itself, matching Robinson (2011) who argues that "The educational value of creative work lies as much on the process of conceptual development, as in the creation of the final product." (p.278). But there are potential consequences here for creativity, whilst the end result might be satisfying for the students, the lack of recognition from the broader *field* (Csikszentmihalyi, 2013) might prevent student work from being accepted as creative.

Students did appear to care about other people's views of their films, even if the films weren't made for other people. Derrick felt his team had been successful: "People actually knew what the story was, which sometimes has been problematic sort of, 'I have no idea what went on there'. So we actually got the story across and I think we got an emotional response as well from some parents". Jake also reflects on audience reaction: "Well, it's got one dislike [on YouTube], which I mean certainly someone thought it was criminal, but I think everyone enjoyed it on the night. The audience were laughing. They were into it", see figure 7.11. But went on to argue for the importance of the process of making: "I know that everyone enjoyed making it, so I'd say it was pretty successful".

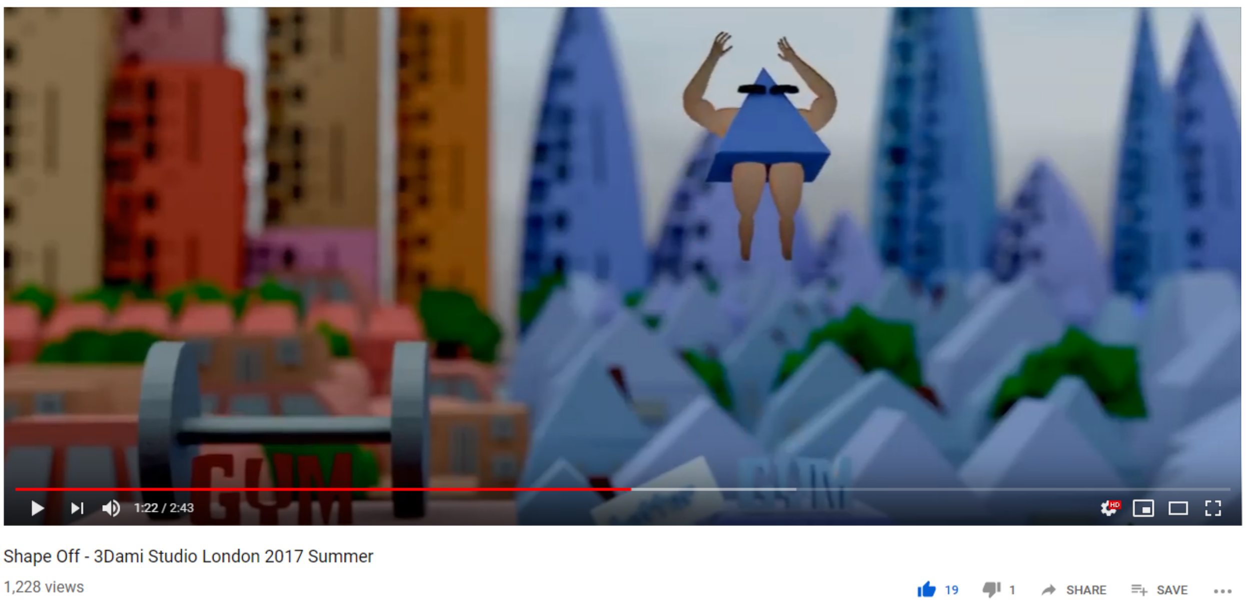

Figure 7.11: *Shape Off* online video views and likes

Whilst the end goal of creating a film within seven days was very clear, the lack of an explicitly defined audience might be seen as a flaw of the course. As a form of media education this makes 3Dcamp sit outside current definitions (e.g. Buckingham, 2003; Burn & Durran, 2007). Herbert notes: "I don't think we were thinking too much about the audience, and that might be a weakness of the film in some way". The question here is whether telling students about a set audience would have allowed them to focus their films better and made better use of established signifiers, or whether stressing the importance of audience would have curtailed the richness of the discourse, design and production process.

7.5.2.3 The mixing of old and new domains One of the difficulties of studying students who are being *digitally* creative is choosing which subject domains to look at (Sefton-Green, 2013). The use of computers is central to the 3D animation making discourse and media production is now largely a digital process (Manovich, 2013). Should we be evaluating film literacy, or the use of software, or both? Much of the current literature ignores or gives limited space to the use of tools and their impact on the implementation of student ideas. Sefton-Green (2013) argues computational thinking should be part of the discourse of *digital* creativity and, as seen above, I have used computational thinking as a means of understanding the creative process of students making 3D animated films, outlining some of the affordances (and constraints) for film making provided by digital technology. This has put the use of technology at the centre of discussion about student 3D animation (Sefton-Green, 2005). In addition I adopted the multimodality model of Kress (2009) to look at the discourse, design, production and distribution of the films. I argue here that these two models are not separate and I outline how they interact and influence each other, arguing that research into 3D animation, and other media making, should include both multimodality and computational thinking models.

Student selection of appropriate signifiers when designing the elements of a 3D animation saw parallels with the work of Burn & Kress (2018), with design choices being influenced by student's previous experience of culture and their interaction with the technology assets at hand. Cultural influences are clearly visible in the interviews, with several students referencing recent films in their choices of colours schemes and character designs (e.g. Moana, SpongeBob SquarePants). My focus here is on how technology influenced the design of the films. As argued above, in *Software*, the program used for the film, Blender, can be considered to be a *expression complete* product as the artistic outcomes of the product are almost unlimited, given the correct hardware resources. However, some actions in Blender will be easier than others due to the design of the software interface. Blender's affordances will vary from other similar software, and be highly dependent on how skilled students are with this tool, i.e. what do they know how to do rather than what could they theoretically do (Norman, 1988). Corresponding with this, none of the 3Dcamp students said anything was impossible due to software, instead they made design decisions based on the *time* available, the *computing power* they would have access to, the *skillset* of the students that were working with them and the *expectations of the course*. As well as mentioning the difficulty of using the software for beginner users. I argue here that in addition to cultural influences, student signifier choices are a function of their understanding of time available, computing power, software, peer skillset and course expectations. This expands on Sefton-Green (2005) who argues that "software structures the way young authors conceptualise the medium" [p.1]. We cannot treat software on its own, it is subject to the hardware it runs on, the time pressures around its usage and the skills and knowledge of the software possessed by those using it. For 3D animation, I argue that ‘skills and knowledge’ include (potentially tacitly) computational thinking, which I will now expand on.

Time and computing power limitations led students to use a range of computational thinking concepts in their design decisions. Firstly, several students mentioned that design of assets often led them towards “low poly” models, with low poly modeling being a form of *abstraction* through *information neglect* (Colburn & Shute, 2007), influenced by the skill set of their teammates and by the knowledge of the time it would take to render more detailed models. *Pattern recognition* was used by students looking to use the same base model multiple times, for example when planning to build a forest without having to model each tree or construct a city without having to model each building individually, or make a crowd quickly. Knowledge of the *automation* capabilities of Blender allowed designs to include simulations and other built in tools that sped up the process of creation, for example knowing about the array modifier allowed for the design of long strips of fencing (there would be no need to model each plank individually), knowing about the particle simulation allowed a design to include a flock of sheep (you didn’t need to animate each sheep individually), see figure 7.12.

Additionally, the skillset of fellow team members influenced the design process directly, with producers and directors designing their films based on what they thought their peers could realistically create. This involved the computational thinking concept of *decomposition*, breaking the film into components that could be later brought together by linking, then assigning these individual tasks to individuals based on their skills. This clearly supports the use of computational thinking within 3D animation, supporting the expansion of the domain of computational thinking beyond computer science (Barr & Stephenson, 2011). It should be noted that the use of computational thinking here demonstrated the near complete absence of the development of algorithms, which are seen to be an essential component of computational thinking (Selby & Woollard, 2013) and a key part of digital creativity (Sefton-Green, 2013). All teams here used automations in their films, and whilst algorithms are examples of automations, it is clear that digital creativity can exist with automations made without algorithms.

Without the use of these computational thinking concepts, designs might have been created that were not feasible within the constraints of the production process, either they would run out of *time* to implement designs, the computers they used would not be *powerful* enough, their *team* wouldn’t be able to implement their plans, or the *software* would be incapable of actioning their plans.

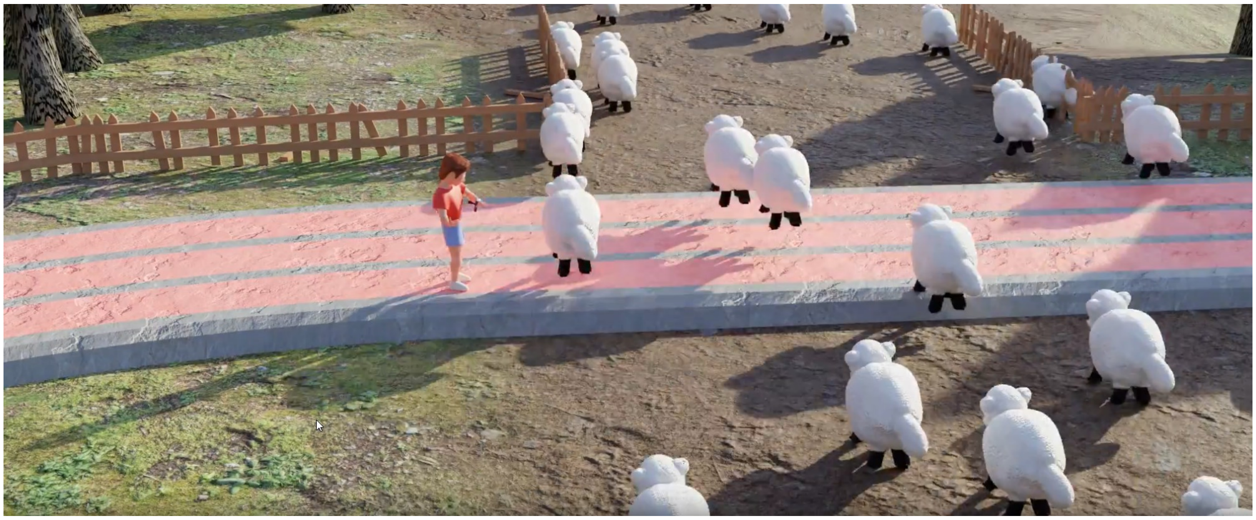

Figure 7.12: pattern recognition, abstraction and automation used when designing the sheep component of *render farm*

Production clearly has links with computational thinking, and the research question: *What possible connections are there between computational thinking and multimodality in the production of 3D digital animation?* can be read as an exposition of how computational thinking is used in the production part of student film making.

Distribution might be argued to incorporate the *rendering* of the final film product. As such this element of multimodality links in with computational thinking concept of *abstraction*: how can shots be reduced in detail to shorten render time, how can the resolution be reduced to make the shot look ok but take less time to raytrace, and how can final frames from shots be repeated to make longer shots without having to use any more render time. Evaluation is a large part of distribution. As noted above, the lack of an explicit audience for 3Dcamp films means that external evaluation was not a key element of the course. However, students were building a film that was to be displayed to a real audience, even if it was only themselves, linking in with the constructionist theory of learning (Papert & Harel, 1991) with require the creation of a public artefact, with some examples of students going back and adapting the original film files to make remixes at later dates. The accessibility of original film files links in with the constructionist idea behind the Scratch programming language, where it's not just the end game/animation that is shared, but the code behind it, allowing for the remixing of other people's projects (Resnick et al., 2009).

Burn & Kress (2018) compare their students' work and work produced in industry, noting that "the basic principles are very similar" (p.15). I argue here that such a statement might be correct if using a more traditional discourse of film creation, e.g. you can see attempts at use of different forms of lighting and timing. Within a digital creativity framework the exclusion of explicit computational thinking concepts from the analysis of student work suggests that there might be principles missing in many school based film projects, either absent from curriculum, pedagogy, student practice or assessment models. It should be noted that computational thinking does not appear in any of the formal Media Studies curricula in England (e.g. OCR, 2018). Within 3D animation the choice of semiotic signifiers is deeply influenced by computational thinking concepts and the computing ecosystem within which a film is created (i.e. is what is being asked possible with current technologies), therefore parallels between work might be weak if students and industry are using very different tools. The limitations that the combination of software and hardware place on student expression remain underexplored within the literature.

Additionally the claim of Burn & Kress (2018) that "the basic principles are the same" (p.15) fails to figure in the added complexity that team working on large computer based projects brings. 3Dcamp has teams of 9 students, with directors and producers noting a host or problems related to team management. Film making research within school and extracurricular clubs is often focused on pairs of students or individual makers. This does reflect some work within the industry, but a lack of focus on group dynamics misses important components of semiotic choice. For example, signifiers might be chosen that a director knows to be achievable by other team members, or signifiers might be chosen as the result of part of a discussion with a wide group of other students.

Within youth film research another factor needs to be taken into consideration: the discourse of youth film camps. Several of the students interviewed had attended the camp before and the tacit and explicit expectations were repeatedly referred to when deciding on the *discourses* that would be present in the film. It was the course that influenced how many characters they should include and students on the course assumed that comedy was the easiest form of film to make with the available resources. Team size and composition also shapes the discourse, for one or two students working together might lead to different choices than teams of 9.

7.5.3 Student definitions of creativity

Students definitions of creativity were closely aligned to descriptions present in the *person* component of the systems model of creativity (Csikszentmihalyi, 2013) and highlighting the need to create things that are new (e.g. Robinson, 2011). Catherine: "It's the ability to imagine and be able to create something that's unique, and you've created yourself", Sazia: "I feel like creativity is the freedom to expand your own thoughts, to go and make things, and to do things in the direction that you wish, not what other people tell you", and Teresa: "Being original, thinking for yourself". Teresa went on to say that creativity in some subjects could be seen as "[t]hinking of a way of getting around problems. That's in a way being creative. Trying to solve problems, thinking of ways of solving problems that you have to do in science", which links in with the problem solving nature of creativity defined by Craft & Jeffrey (2008), where creativity can be on the 'ordinary' level, solving problems which impact one's own life, and not necessarily other peoples'.

Teresa took this slightly further, talking about her attempts to convert Kafka's philosophical concepts into her own personal animations, mentioning that: "it's important to be aware of other things [...] I think all the good stuff I've seen is very rounded from people who are open minded". Supporting theories around creativity involving combining *domain* ideas or concepts outside the immediate creative space you are working in (Csikszentmihalyi, 2013).

Very few students mentioned any kind of verification process for judging whether acts were creative or not. The *field* component of the systems model of creativity (Csikszentmihalyi, 2013) was only touched on briefly by Burt who mentioned the importance of personal satisfaction in creativity: "Making something your own. Taking tools and manipulating it into something that you've created, into something that you like". This again links to Craft & Jeffrey (2008) and their 'ordinary' level of creativity, where the creative outputs are to suit the needs of an individual rather than address the wider needs of society; no attempts were made to talk about the wider social understanding of creativity, and the need to engage with larger groups of people in verifying creative acts.

For some students there were courses that they considered to be creative and those that they thought were less creative. Catherine drew a line between technical and creative courses: "I guess art, and all the kinds of art, like music, art, graphics, and animation, that's kind of creative. Then there's the more technical stuff like, science, math, computer science". Sazia was more inclusive: "[all subjects are creative] to an extent, depending on how it's approached. So in computer studies and stuff, if you're given more rein, more freedom ... If you're not given limitations, it's easy to be creative. But in stuff like science, obviously, there's a lot of limitations. So there's no room for creativity, pretty much". As was Teresa: "I'd say all subjects could have some kind of creativity in them. I'd even say in mathematics [...] but I guess some subjects are more creative than others". Catherine suggested that: "you need a mixture of science and art to make something really creative".

Amy commented that amongst the students on the course: "you could tell who were more technical than artistic and vice versa". No attempt was made to get students to explain the difference between creativity and *digital* creativity (e.g. Sefton-Green, 2013), however Catherine did describe the difference she saw in people who were creative or technical, and how this manifested itself in terms of creativity: "if you're into the more technical stuff, you probably will do computer coding [...]. But if you prefer not to do the technical stuff, and you prefer more in the creative side, then I guess you'd do animation".

7.6 Conclusion

This chapter's aim was to outline student creativity through analysing their interactions with the field that influences 3D animation, and their understanding and implementation of domain specific skills through the study of computational thinking and multimodality. I now cover these areas by looking at how each of the research questions have been addressed:

2. What are the affordances of 3D digital animation work for young people?

I argue that the affordances of 3D digital animation are subject to the function of student social and cultural backgrounds, the time available, the software product used, the computing power students have access to, the skillset of the students that were working with them and the expectations of the course.

It can be argued that by using a tool such as Blender, students would be able to access a rich set of semiotic signifiers. I argue above that this set of signifiers might be considered to be *expression complete*, in that the Blender could possibly represent any artistic output. However, we cannot consider the affordance of a tool outside the constraints within which it is used (McGrenere & Ho, 2000; Norman, 1988). The possibilities available to students when creating with 3D animation were a result of a range of factors, including the cultural, societal and technical.

Students access to 3D animation was heavily influenced by the presence of older people around them. In most cases this was the support of a teacher or a parent, some students also mentioned siblings who were helping them, this matches the research of Sefton-Green & Brown (2014). Within their 3D animation practice most students were lone practitioners. Whilst some students were involved with the creative endeavours of their peers, they were usually the only people amongst their friendship groups to be doing 3D animation. Several students thought that their peers were put off by the complexity and technical nature of the software used, linking in with ideas of gendered forms of digital creativity seen elsewhere (e.g. Wong & Kemp, 2018; Quinlan, 2015). Formal school based support for 3D animation was entirely absent in the interview cohort, with teachers generally showing interest and support, but unable or unwilling to provide lessons or clubs. There were examples of students submitting 3D animation work as part of formal assessments, but again, they were alone in doing this and doing so without the help of teachers. Most students were getting most of their learning materials through online platforms, matching the model of digital creativity posed by Sefton-Green (2013). The affordances of 3D animation are both subject to the gatekeepers of that domain knowledge in the formal and informal education, and democratically available through online resources, albeit some of them requiring financial input.

3D animation was seen as being more inclusive than other computing and media related courses as it brings together technical and 'creative' aspects, which appeal to a wider audience. Many students were of the opinion that artistic/creative subjects are more appealing for females and technical courses more appealing for males, backing up these claims by referencing the subjects groups in their own schools. This observation correlates with national datasets (e.g. Kemp et al., 2018). This idea of mixing technical and artistic components of digital creativity to create a more gender neutral learning space is supported by literature on inclusion (Wong & Kemp, 2018) and STEAM (Colucci-Gray et al., 2017). Students didn't perceive any differences in male and female aptitudes in subjects, counter to one interpretation of study one. Several students attributed success to student effort alone and that girls and boys could achieve in 3D animation if they wanted to. Students were largely of the opinion that different cultures set different expectations on their children, which they thought might explain the differences in uptake of different courses. As such 3D animation potentially offers females a more inclusive way into digital creation than other more 'technical' modes of expression.

Most students argued that it took a significant financial investment to be properly involved with 3D animation, with costs coming from hardware, software and training. Parents were the main source of money, with one student borrowing from their mum and dad, and another using inheritance money. These forms of *economic capital* (Bourdieu, 1986) not being equally available to everyone. Whilst the software might have the potential to create almost anything, the hardware used by a student to do so will place constraints on the outputs of the software. In this sense 3D animation offers almost unlimited expression, albeit tempered by the funds you have available to invest in the necessary hardware and training.

From the above, I argue that the learning pathways for young 3D animators are often informal, solitary, student led, yet supported by the *field* of family, friends and/or teachers. Where pathways do exist they are seen as inclusive in terms of gender but exclusive in terms of the need for financial investment.

Several of the tools available for 3D animation do not allow students to create commercial outputs. Blender, the open source tool used in 3Dcamp, did allow you to sell your work, as described by one student. Whilst 3D animation might allow someone to start making the media that they also consume, we cannot talk about full democracy in media making until we take into account the *external expression* of the tool, i.e. what you are allowed to output.

3. What possible connections are there between computational thinking and multimodality in the production of 3D digital animation?

Media creation is increasingly a digital pursuit, with 3D animation being a prime example of the merging of computing technologies and media literacies. These two domains cannot be treated separately. With the medium of expression largely computer based, semiotic decisions take place through and in conversation with computing, but are also influenced by the constraints and affordances of computers. Within 3D animation, we must consider how computational thinking influences the the decisions that are involved in multimodality. Additionally, we cannot consider computational thinking to happen without context and the multimodality adds a rich framework to which computational thinking concepts can be applied.

Computational thinking is seen as a key component of digital creativity (Sefton-Green & Brown, 2014), and this chapter outlines how the concepts of abstraction, algorithms, decomposition, pattern recognition, automation and evaluation are used in 3Dcamp. I then go on to outline how computational thinking interacts and complements multimodality.

Information loss abstraction (Colburn & Shute, 2007) is seen throughout 3D animation, both in terms of artistic expression and as an attempt to reduce complexity so that usable 3D assets can be made within the limited time and computing power available. *Information hiding* was also seen in student practice through the use of *linking* and *layers*. These forms of abstraction are not well documented in the literature which mainly focuses on the use of functions and procedures as seen in computer programming.

Decomposition is used when breaking projects down into components that other team members can make. Pattern recognition was used as a way of reusing and reappropriating other assets.

Algorithms were far less evident in student work that in other computational thinking animation projects such as those using Scratch or Alice (e.g. Cooper et al., 2000; Dann et al., 2008; Hart et al., 2008), this is probably because these other tools are *programming* environments whilst a tool like Blender relies less on programming and more on the use of inbuilt visual tools such as sliders and buttons. Where programming/algorithms were seen in 3Dcamp it was through the use of node based editors, a form of programming largely absent from the literature. There are suggestions about how computational thinking can be used beyond computers (e.g. Barr & Stephenson, 2011), the question that this chapter raises is how computational thinking differs between building automations through programming interfaces and those which are built without the user constructing an algorithm, e.g. where they use the graphical user interface.

Whilst the literature doesn't always argue for automation being a key component of computational thinking (e.g. Selby & Woollard, 2013), my research found that automations were a key part of students making films. Where automations are normally assumed to be an implementation of an algorithm, 3D animation uses a variety of automations that don't follow user made algorithms, for example the use of modifiers to add or subtract detail from models, or the use of physics simulations with parameters.

Evaluation often involved seeing whether the desired automation was possible with the given time and computer power. All students met issues with *rendering* their shots, meaning they were always keen to use other computational thinking concepts to speed things up. The drive towards efficiency and balancing outputs and performance effects even the beginner student. And I argue that 3D animation helps open up new areas of computational thinking as facing the constraints of the computing power available to a student is very rare in beginner level programming courses.

By looking at how the theory of multimodality (Kress & Van Leeuwen, 2001) was used by 3Dcamp students, I find a range of influences on student discourses, design and production. These influences include the culture of the students and the technology available, matching those mentioned by Burn & Kress (2018), but also expanding on them. The choice of discourse and signifiers was heavily influenced by the student understanding of the available technologies, i.e. software and computing power, and how solutions might be implemented in the time available, within the expectations of the camp, using the skillsets of team members. Decisions about what could and could not be implemented within these constraints included the heavy use of computational thinking. This matches and expands on Sefton-Green's (2013) argument that the study of *digital* creativity, e.g. the making of media using technology, should include an understanding of computational thinking.

Examples of the use of computational thinking informing media literacy decisions include: pattern recognition allow students to design one character that could be used multiple times, i.e. students felt able to create films with multiple characters; limitations of computing power influencing the style of film that students felt able to complete in the time available; and information hiding through the linking of multiple assets together to make a film allowing for students to split the creation of film assets across multiple students, increasing the complexity and range of signifiers students were able to use.

Students films were produced with little thought given to the audience. The lack of thought given to this important component of media literacy (e.g. Buckingham, 2003) appears to be a function of it being largely ignored by the camp pedagogy. Whilst this might be seen as a serious omission, it might also be considered beneficial to students who, rather than focusing on making something for other people which entails meeting a range of conventions, were focused more on the process of making. Noting the lack of audience raises another important component in understanding youth media product, the discourse of the course. Several students were at the camp for the second time, bringing with them a tacit understanding of the expectations of the camp that were not present in the camp teaching content, these included an understanding of what they thought possible within the timeframe of seven days with students of varying competencies, and what they understood the hardware to be capable of. These limitations led most students to adopt comedy as their film genre, clearly showing how the discourse of the camp led directly to choice of discourse in the film.

I argue that modern digital media creation cannot be fully understood unless the domains of computational thinking with multimodality are taken into account. And the affordances of 3D animation are subject to the *time* available, the *software product* used, the *computing power* students have access to, the *skillset* of the students that were working with them and the *expectations of the course*.

8 Finale

The overall objective of this thesis was to understand the role of 3D animation in supporting the development of digital creativity". It did this by outlining the current routes through which students are creating things digitally, by looking at the concepts of STEM and STEAM and outlining recent changes in the English national curriculum to focus more on computer science and computational thinking. It outlined the gendered nature of computing in school and looked at the decline of the arts as a curriculum subject. Literature on what it is to be creative was explored, with a focus on Csikszentmihalyi's (2013) systems model of creativity. Specific literature on digital creativity was outlined. Arguments were presented for a project based model of learning based on *constructionism* (Papert & Harel, 1991), along with arguments on why it is important for students to study 3D animation.

The knowledge and skills domain of 3D animation was explored by looking at media studies and computing. Media literacy was outlined, looking at the semiotic model of multimodality (Kress, 2009); as was computational thinking, focusing on the definition of abstraction, algorithm, automation, decomposition, pattern recognition and evaluation. In addition the tools used for 3D digital animation were studied, looking at the impact of software choice on student creation. Building on ideas of affordance (Norman, 1988), I developed two different criteria for digital expression that should be considered when selecting software for an educational project, *internal* expression, the range and richness of artistic modes that can be created within a tool, and *external* expression, the range of outputs that a software tool can create. I introduced the idea of *expression complete*, where a tool is able to represent any artistic mode.

The 3D animation camp being studied was outlined mapping it against models of creative pedagogies. Finally, three research questions were posed which are answered in study one, the analysis of national exam statistics for CS and Media studies, and study two, the analysis of students attending a 3D animation summer camp. I will now outline my findings against each of these questions:

1. What characterises the opportunities for learning 3D animation in the formal curriculum?

Study one looked at the GCSE computer science and media studies courses. Provision of media studies was focused largely in comprehensive schools, with CS being equally popular in comprehensive and grammar (selective) schools. The gender type of a school appears to have little impact on provision of Media studies, whilst all boys schools were substantially more likely to offer CS. Generally schools serving richer communities were more likely to offer CS than those serving poorer communities, for media studies, the richest schools were substantially less likely to offer the subject than their counterparts serving poorer communities. Poorer girls were significantly more likely than their richer peers to be studying CS, with the reverse being true for

Media Studies. There is a huge disparity in grade outcomes, with students performing more poorly in CS than other subjects and media studies being one of the subjects where students were most likely to achieve higher grades than their other subjects. Study two provided an example of the potential impact of this, with a teacher telling their students not to take qualifications in Media Studies, as they considered it an easy option. Both exams appear to be gendered, with males outperforming similar ability females in CS by nearly a third of a grade, and females out performing similar ability males by 0.4 of a grade in Media studies. Females taking CS and Media studies got on average nearly one and a half grades more in Media than they did in CS. I speculate that this disparity in grades will lead to decreased self-efficacy (Huang, 2013) for females in CS, potentially explaining why they don't choose to study the subject at higher levels of education. Computing and media studies have seen a steep decline in hours taught at secondary school, suggesting that formal opportunities for students to access the skills underlying 3D animation are narrowing.

2. What are the affordances of 3D digital animation work for young people?

Study two found that 3D film creation choices were heavily influenced by the cultural experiences of children's lives with many students naming specific films that had influenced their own choices of signifiers, as well as the material assets available to the students. This confirms the observations of Burn & Kress (2018). Student responses allowed for an expansion of what is meant by *material assets*, looking at the interrelation of software, hardware and individuals. The use of Blender, industry standard 3D animation software, can be seen as giving students an *expression complete* tool, in that any visual artistic output could be created given enough time and resources. However, the affordances of the software are not solely based on the potential coded into the software, they are a result of constraints placed upon the software by the users and the hardware it runs on, matching Norman (1988) who argues that affordances are dependant on the situation where systems are used, not just the theoretical potential. All teams ran into rendering issues often having to cut down the complexity of what they were trying to demonstrate, clearly showing that whilst the tool might have been expression complete, the affordances of the tool were less than that, restricted by the hardware setup available and the time available to render things. More powerful hardware would have allowed for a richer range of signifiers. Additionally producers and directors made artistic choices based on the skill set of their team members, tempering their expectations to match what they thought could be achieved. Several students also placed restrictions on their work based on their understanding of the course expectations, for example picking comedy as a genre as they thought it would work in the time available. As such I found the affordances of 3D digital work to be a function of cultural experience and tool usage restricted by *time* available, *software* features, *computing power*, the *skillset* of other team members as well as the understanding of course expectations.

Cultural experience that impacts student signifiers include students' own education. Study two showed that 3D animation skills largely self taught in informal environments. Where students were able to link 3D animation in with formal qualifications they did so without the technical support of teachers, they were allowed to use 3D animation but they were alone in learning it. Nearly all students were supported by family and/or by teachers, who, lacking the subject knowledge themselves were often able to direct students to resources and extra curricular activities. This matches the findings of Sefton-Green & Brown (2014) who also note the importance of adults in the backgrounds of the digital makers that they studied. Just because a tool exists does not mean it is accessible to create with it, with barriers to entry around the perceived difficulty of using a tool and the hardware required to use the tool. Financial support was often required to be involved in 3D animation, with many students suggesting that expensive computer hardware and access to paid for tutorials was required to be proficient. Whilst 3D animation development has been largely democratised through the greater availability of professional tools to consumers, matching observations about other forms of media creation such as video editing (Buckingham & Sefton-Green, 2005); there are still significant hardware costs involved which are less present in other forms of digital creativity such as python programming. 3D animation was seen by students to be a good mix of computing and media skills and a broader interpretation of computing to include art elements was seen to support better female uptake (Wong & Kemp, 2018).

3. What possible connections are there between computational thinking and multimodality in the production of 3D digital animation?

This thesis argues that we cannot look at media studies as being based solely in the traditional domains associated with media literacy, in this case multimodality. The changing nature of media production means it has largely become a form of digital creativity (Manovich, 2013). This research provides detailed empirical data that showcases how 3D animation utilises computational thinking in creating films, providing evidence for the definition of digital creativity given by Sefton-Green (2013) and a full exposition of how computational thinking can be used in creating 3D animations, confirming and expanding the theoretical and preliminary work of Kemp (2014a) and Perković et al. (2010).

Computational thinking concepts can be mapped to 3D animation, with each element clearly seen in the production of 3D films. Automation is a key part of 3D animation creation, often performed by students through the use of inbuilt software functions and often without creating algorithms. Efficiency of solutions is key for 3D animation especially when the final render of a film was being made. Students often met the limitations of the hardware they were using, an uncommon occurrence in more traditional programming examples of computational thinking. The data here argues for the importance of automation in 3D animation, often without algorithms, conflicts with definitions of digital creativity (Sefton-Green, 2013) and computational thinking (Selby & Woollard, 2013), which argue for the central position of algorithms, programming and coding.

The elements of multimodality were clearly seen in the creation of 3D films on the camp. Discourses, designs and production were informed by student's existing knowledge of other media products, as well as the explicit and tacitly understood rules of the camp, including the constraints of the camp length, the team skillset, the software used and the hardware available. Additionally, computational thinking heavily influenced the choice of signifiers and how they were created, which also influenced the choice of discourse for the films.

In conclusion

3D animation demonstrates the deep interaction of computing and media concepts. Media studies should look to adopt more elements of computing, in particular computational thinking, to better understand the work being created and the process that leads to the choices of discourse and signifiers; computing should look to adopt media and arts related components to help broaden its appeal. As digital media takes a tighter grip on our everyday understanding of the world and 3D animation makes up a larger part of digital media, it is important that students have access to opportunities to learn how 3D animations are constructed allowing them to better critique the world around them. However, formal pathways for digital creativity appear to be narrowing in the English education system, and 3D animation still has significant financial barriers for student access.

8.1 Limitations

This thesis used two studies to form its conclusions. Whilst both studies were rigorously executed the results should be read with caution.

The focus of study one was predominantly on the English national GCSE examinations in computer science and media studies. Other courses related to 3D animation could have been selected, for example design and technology, and art. Additionally, there are some specialist non-GCSE courses which cover 3D animation explicitly, albeit with very low uptakes, these courses are not covered here. Courses at A-level and degree level were not looked at, these are the levels of study where large numbers of students *do* specialise in 3D animation courses. However, the choice of subjects does give you a picture of the flagship course for digital skills at age 16 in England, GCSE CS, and the main course for moving image related skills, GCSE media studies. I think the choice of courses is a fair representation of the major subject areas encompassed in 3D animation.

In the future other GCSE subjects and other levels of qualifications could be studied, as could courses in other countries. This would allow for a broader understanding of 3D animation in other contexts.

The focus of study two was on interviewing 3D animation students. These students were self selecting and only a subset of the students that attended the 3Dcamp course, comprising 12 interviews in total. Whilst I can't claim that this sample is representative of the country, it was able to describe the running of the camp and the media products created as the students interviewed were mainly the producers and directors, students who were working intimately with other camp attendees and responsible for final outcomes. Additionally, the research had a focus on 3D animation, and students of the age 11-18 doing 3D animation appear to be very uncommon. Therefore interviews with this group gives us a rare insight into this specific group of digital makers.

Due to time and space restraints, the focus of the research was largely on the domain and field of Csikszentmihalyi's (2013) systems model of creativity, with only literature references to the person component covered. This thesis would benefit from the assessment of personal factors of creativity, and the study of how these factors interacted with the field and the domain in allowing students to become digitally creative.

8.2 Implications for policy and practice

Media education needs to recognise computing competencies in the form of computational thinking and the impact of software and hardware on student choices and outcomes. This has implications for media courses in schools which, whilst they might use technology in production, do not currently reference computational thinking (e.g. AQA, 2017).

Within media production research, the impact of technology on design is recognised by some (e.g. Burn & Kress, 2018; Sefton-Green, 2005). My thesis expands this recognition and argues for the importance of software, student skillset, time available, and computer hardware in student use of film semiotics. Additionally I argue for the recognition of the discourse of any course that is being studied, and the impact of this on student signifier selection. All these elements should be taken into account when building courses and evaluating student outcomes.

Where media research and media education talk about the democratising nature of new technologies in making production techniques available to the masses (e.g. Manovich, 2013; Burn & Durran, 2007) , there should also be a recognition of the costs of tools. This cost involves the money required to purchase software, the hardware requirements of the software and the ability to make tools available to students at home, as well as allowing them to create a range of commercial outputs (this is incorporated in my definition of the *external expression* of a tool). I argue that production techniques in formal education should try to use open source or free software where possible if we are to be truly talking about the democratisation of media production.

Skills in 3D animation cover a range of important media artefacts for students. 3D animation and related 3D technologies are present in television, games, film and 2D media. There are a lack of opportunities within the formal school curriculum for students to learn the skills involved in 3D animation. Opportunities should be created within the computing and media studies subjects for students to learn 3D animation techniques.

Computing and media studies are in decline in schools, potentially because of government school metrics such as Progress 8 (Steers, 2014). Government should look at driving forces within schools to encourage greater access to these courses. In particular they should look at ways to engage more females in computing, such as adopting a STEAM interpretation of the subject through the inclusion of art elements such as 3D animation. The current GCSE in computer science looks likely to disengage a large number of females and poorer students, especially now that it is the only computing GCSE available. The introduction of a broader *computing* course could help make the subject more accessible and cover skills that more students would need in everyday life.

Disparities in subject results means students, especially girls, will be disproportionately put off computer science as they do very badly in CS compared to their other subjects. There is an urgent need for the government to look at how grade boundaries are set for the GCSE CS course. Additionally media studies appears to be too easy. Work should be done to align both of these subjects with other GCSEs.

8.3 Suggestions for future research

This research attempted to link computational thinking with multimodality. Further work is needed to see how computational thinking can be used in the production of other media outputs including 2D animation, film and sound.

The impact of tool choice and hardware limitations in school aged media production needs to be better understood. How the choice of tools enables and limits creative outputs will help understand the true nature of the democratisation of media through digital technology.

Disparities in female and male achievement between subjects needs to be explored. How these gendered results manifest themselves through individual examination questions and different types of coursework needs to be better understood. What would a gender neutral computer science and a gender neutral media studies assessment model look like?

What are the reasons for schools dropping media studies and computing curriculum time? How could schools be incentivised to increase the time allocated to these courses?

Further research into the specific websites and resources used by beginner 3D animators needs to be better understood. A wider range of young 3D animators needs to be engaged to find out if the patterns of pathways noted above hold true, this includes students from other countries and cultures.

If we are to look at formalising 3D animation teaching we need to better understand the best pedagogical models for this. This includes studying existing formal and informal curricula.

I have shown how computational thinking is used in 3D animation, with differences from computational thinking seen in computer science and programming. How is computational thinking used in other areas of media production and how does the use of computational thinking seen in software development differ from computational thinking in software usage?

Whilst I have focused on studying the domain and the field of the systems model of creativity, further research is needed into the personal attributes of digital creators making 3D animations. How do psychological factors influence the uptake and proficiency in making 3D animations?

The changing nature and increasing digitisation of media production means that we need to recognise the central importance of student interaction with 3D animation and computational thinking. The present thesis gives one of the first descriptions of mapping computational thinking to multimodality, as well as one of the first studies of student 3D digital animators. The democratisation of 3D animation and computational media creation involves gaining a better understanding of how students consume, create and critique; and for that further research in this area is paramount.

9 Bibliography

Ackermann, E. (2004). Constructing knowledge and transforming the world. In M. Tokoro & L. Steels (Eds.), *A learning zone of one's own: Sharing representations and flow in collaborative learning environments* (pp. 15–37). Oxford: IOS Press.

Ackermann, E., Gauntlett, D., & Weckstrom, C. (2009). Defining systematic creativity. *LEGO Learning Institute*. Retrieved from https://web.archive.org/web/20100204224851/http://learninginstitute.lego.com/en-gb/Research/Systematic%20Creativity.aspx

Adams, J. L. (1980). *Conceptual blockbusting: A guide to better ideas.* New York: WW Norton & Company.

Albert, R. S., & Runco, M. A. (1999). A history of research on creativity. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 16–31). Cambridge University Press.

Aleman, A., Bronk, E., Kessels, R. P., Koppeschaar, H. P., & Honk, J. van. (2004). A single administration of testosterone improves visuospatial ability in young women. *Psychoneuroendocrinology*, *29*(5), 612–617.

Ambrosio, A. P., Almeida, L. S., Macedo, J., & Franco, A. H. R. (2014). Exploring core cognitive skills of computational thinking. In *Psychology of programming interest group annual conference* (pp. 25–34). England: University of Sussex.

Aoki, M., Joel, W., Ursyn, A., & Pollak, J. (2017). Is this possible?: Massive online inter-institutional student production. In *ACM siggraph educator's forum* (p. 3). Los Angeles, USA: ACM.

Aoki, M., & Koning, W. (2011). US 3D animation school survey. Retrieved from https://media.siggraph.org//education/PDF/US_3D_Anim_Survey_v1.pdf

AQA. (2017). GCSE Media Studies. Retrieved from https://www.aqa.org.uk/subjects/media-studies/gcse/media-studies-8572

Archer, L., Dawson, E., DeWitt, J., Seakins, A., & Wong, B. (2015). "Science capital": A conceptual, methodological, and empirical argument for extending bourdieusian notions of capital beyond the arts. *Journal of Research in Science Teaching*, *52*(7), 922–948.

Archer, L., DeWitt, J., & Willis, B. (2014a). Adolescent boys' science aspirations: Masculinity, capital, and power. *Journal of Research in Science Teaching*, *51*(1), 1–30.

Archer, L., DeWitt, J., & Wong, B. (2014b). Spheres of influence: What shapes young people's aspirations at age 12/13 and what are the implications for education policy? *Journal of Education Policy*, *29*(1), 58–85.

Armstrong, V., Barnes, S., Sutherland, R., Curran, S., Mills, S., & Thompson, I. (2005). Collaborative research methodology for investigating teaching and learning: The use of interactive whiteboard technology. *Educational Review*, *57*(4), 457–469.

Atkin, A. (2013). Peirce's Theory of Signs. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Summer 2013.). https://plato.stanford.edu/archives/sum2013/entries/peirce-semiotics/; Metaphysics Research Lab, Stanford University.

Baars, S., Mulcahy, E., & Bernardes, E. (2016). The underrepresentation of white working class boys in higher education - the role of widening participation. Retrieved from https://www.lkmco.org/wp-content/uploads/2016/07/The-underrepresentation-of-white-working-class-boys-in-higher-education-baars-et-al-2016.pdf

Baer, J. (2010). Is creativity domain specific? In J. C. Kaufman & R. J. Sternberg (Eds.), *The Cambridge Handbook of Creativity* (1st ed.). UK: Cambridge University Press.

Baillie, C. (2006). Enhancing students' creativity through creative thinking techniques. In N. Jackson, M. Oliver, M. Shaw, & J. Wisdom (Eds.), *Developing Creativity in Higher Education, An Imaginative Curriculum* (pp. 142–155). London, England: Routledge.

Bakhtin, M. M. (1981). *The dialogic imagination: Four essays.* (C. Emerson & M. Holquist, Trans.). Austin: University of Texas Press.

Bakhtin, M. M. (1986). *Speech genres and other late essays.* (C. Emerson & M. Holquist, Trans.) (p. 103). Austin: University of Texas Press.

Banaji, S., Burn, A., & Buckingham, D. (2010). The rhetorics of creativity: A literature review. Retrieved from https://www.creativitycultureeducation.org/publication/the-rhetorics-of-creativity-a-literature-review-2/

Banaji, S., Cranmer, S., & Perrotta, C. (2013). 30. What's stopping us? Barriers to creativity and innovation in schooling across europe. *Handbook of Research on Creativity*, 450.

Baron-Cohen, S. (2004). *The essential difference: : Men, women and the extreme male brain.* Penguin, UK.

Baron-Cohen, S. (2009). Autism: The empathizing–systemizing (e-s) theory. *Annals of the New York Academy of Sciences*, *1156*(1), 68–80.

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The autism-spectrum quotient (aq): Evidence from asperger syndrome/high-functioning autism, malesand females, scientists and mathematicians. *Journal of Autism and Developmental Disorders*, *31*(1), 5–17.

Barr, V., & Stephenson, C. (2011). Bringing computational thinking to k-12: What is involved and what is the role of the computer science education community? *ACM Inroads*, *2*(1), 48–54.

Barron, B., Walter, S. E., Martin, C. K., & Schatz, C. (2010). Predictors of creative computing participation and profiles of experience in two silicon valley middle schools. *Computers & Education*, *54*(1), 178–189.

Beck, K., Beedle, M., Bennekum, A. van, Cockburn, A., Cunningham, W., Fowler, M., … Thomas, D. (2001). Manifesto for agile software development. Retrieved from http://www.agilemanifesto.org/

Becta. (2005). Open source software in education. Retrieved from http://oss-watch.ac.uk/studies/external/becta_oss_2005_case_study.pdf

Beghetto, R. A. (2010). Creativity in the classroom. In J. C. Kaufman & R. J. Sternberg (Eds.), *The Cambridge Handbook of Creativity* (1st ed., pp. 447–463). UK: Cambridge University Press.

Bell, T., Alexander, J., Freeman, I., & Grimley, M. (2009). Computer science unplugged: School students doing real computing without computers. *The New Zealand Journal of Applied Computing and Information Technology*, *13*(1), 20–29.

Bennett, V. E., Koh, K., & Repenning, A. (2013). Computing creativity: Divergence in computational thinking. In *Proceeding of the 44th acm technical symposium on computer science education* (pp. 359–364). ACM.

Benton, T., & Sutch, T. (2014). Analysis of the use of Key Stage 2 Data in GCSE Predictions. *Ofqual*. Retrieved from Available%20online%20at:%20https://www.gov.uk/government/uploads/system/uploads/attachment/_data/file/4

BESA. (2019). Key uk education statistics. British Educational Suppliers Association. Retrieved from https://www.besa.org.uk/key-uk-education-statistics/

Beyer, S. (2014). Why are women underrepresented in computer science? Gender differences in stereotypes, self-efficacy, values, and interests and predictors of future cs course-taking and grades. *Computer Science Education*, *24*(2-3), 153–192.

BIS. (2016). *Computer science graduate employability: Qualitative interviews with graduates*. Department for Business, Innovation; Skills, London, England. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/523079/bis-16-114-computer-science-graduate-employability.pdf

Blades, H. (2012). Creative computing and the re-configuration of dance ontology. In *EVA*. Retrieved from https://ewic.bcs.org/upload/pdf/ewic_ev12_s13paper2.pdf

Blender Foundation. (2019). Open source software in education. Retrieved from https://www.blender.org/about/

Blyth, T. (2012). The legacy of the BBC Micro: Effecting change in the UK's cultures of computing. *Nesta*.

Boden, M. A. (1999). Computer models of creativity. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 351–372). UK: Cambridge University Press.

Bogdan, R., & Biklen, S. K. (2007). *Qualitative research for education: An introduction to theories and methods* (5th ed.). Pearson.

Bolgan, S., Mosca, D., McLean, C., & Rusconi, E. (2016). Systemizers are better code-breakers: Self-reported systemizing predicts code-breaking performance in expert hackers and naive participants. *Frontiers in Human Neuroscience*, *10*, 229.

Bordwell, D., & Thompson, K. (2010). Film art: An introduction - 9th edition. McGraw-Hill Higher Education, New York.

Bourdeau, M. (2018). Auguste comte. In E. N. Zalta (Ed.), *The stanford encyclopedia of philosophy* (Summer 2018.). https://plato.stanford.edu/archives/sum2018/entries/comte/; Metaphysics Research Lab, Stanford University.

Bourdieu, P. (1986). The forms of capital, 241–258.

Box, T., Cooper, L., Smith, A., Devereux, S., & O'Connor, K. (2019). Inclusion and Diversity in UK VFX, Animation and Post Production. UK Screen Alliance. Retrieved from https://www.ukscreenalliance.co.uk /news/uk-screen-alliance-releases-ground-breaking-industry-diversity-inclusion-report/

Bramley, T., Rodeiro, C., & Vitello, S. (2015). *Gender differences in GCSE*. UK: Cambridge Assessment. Retrieved from http://www.cambridgeassessment.org.uk/Images/gender-differences-in-gcse.pdf

Brennan, K., Chung, M., & Hawson, J. (2011). Creative computing: A design-based introduction to computational thinking.

Brennan, K., & Resnick, M. (2012). New frameworks for studying and assessing the development of computational thinking. In *Proceedings of the 2012 annual meeting of the American Educational Research Association*. Vancouver, Canada.

British Computer Society. (2018). MOVING ON UP: BCS Analysis of Social Mobility in IT. Retrieved from https://www.bcs.org/category/19304

Brown, N. C., Sentance, S., Crick, T., & Humphreys, S. (2014). RESTART: The resurgence of computer science in uk schools. *ACM Transactions on Computing Education (TOCE)*, *14*(2), 9.

Brugha, T., McManus, S., Meltzer, H., Smith, J., Scott, F., Purdon, S., … Bankart, J. (2009). Autism spectrum disorders in adults living in households throughout england: Report from the adult psychiatric morbidity survey 2007. *Leeds: The NHS Information Centre for Health and Social Care.*

Bryman, A. (2008). *Social research methods* (3rd ed.). Oxford: Oxford University Press.

Buckingham, D. (2003). *Media education: Literacy, learning and contemporary culture.* Cambridge UK: Polity.

Buckingham, D., Grahame, J., & Sefton-Green, J. (1995). *Making media: Practical production in media education*. London, England: English and Media Centre.

Buckingham, D., & Sefton-Green, J. (2005). *Cultural studies goes to school*. London, England: Taylor & Francis.

Bundy, A. (2007). Computational thinking is pervasive. *Journal of Scientific and Practical Computing*, *1*(2), 67–69.

Burn, A. (2007). The Place of Digital Video in the Curriculum. In R. Andrews & C. Haythornthwaite (Eds.), *The SAGE Handbook of E-learning Research* (1st ed.). London: SAGE.

Burn, A. (2009). *Making new media: Creative production and digital literacies*. New York: Peter Lang.

Burn, A. (2013). The kineikonic mode: Towards a multimodal approach to moving image media. *NCRM Working Paper*. Retrieved from http://eprints.ncrm.ac.uk/3085/

Burn, A. (2014). Digital aletheia: Technology, culture and the arts in education. In A. King, Himonides E, & A. Ruthmann (Eds.), *The Routledge Companion to Music, Technology & Education*. London: Routledge.

Burn, A. (2016). Making machinima: Animation, games, and multimodal participation in the media arts. *Learning, Media and Technology*, *41*(2), 310–329.

Burn, A., & Durran, J. (2007). *Media literacy in schools: Practice, production and progression*. London, England: SAGE.

Burn, A., & Kress, G. R. (2018). Multimodality, style and the aesthetic: The case of the digital werewolf. In *Multimodality and aesthetics* (pp. 15–36). Routledge.

Burn, A., & Parker, D. (2003). *Analysing media texts*. London, England: Bloomsbury Publishing.

Burns, R. B. (2000). *Introduction to research methods* (4th ed.). London: SAGE.

Burr, V. (2003). *Social constructionism* (2nd ed.). East Sussex: Routledge.

Butler, J. (1990). *Gender trouble: Feminism and the subversion of identity*. London, England: Routledge.

Byrne, P., & Lyons, G. (2001). The effect of student attributes on success in programming. In *ACM SIGCSE Bulletin* (Vol. 33, pp. 49–52). ACM.

Caspersen, M. E., Gal-Ezer, J., McGettrick, A., & Nardelli, E. (2018). *Informatics for all: The strategy*. ACM Europe Council, Informatics Europe. Retrieved from https://www.acm.org/binaries/content/assets/public-policy/acm-europe-ie-i4all-strategy-2018.pdf

Catterall, L. G. (2017). A brief history of STEM and STEAM from an inadvertent insider. *The STEAM Journal*, *3*(1), 5.

Chaiklin, S. (2003). The zone of proximal development in Vygotsky's analysis of learning and instruction. *Vygotsky's Educational Theory in Cultural Context*, *1*, 39–64.

Clements, D. H., & Sarama, J. (2003). Strip mining for gold: Research and policy in educational technology—a response to "fool's gold". *AACE Journal*, *11*(1), 7–69.

Coe, R. (2002). It's the effect size, stupid: What effect size is and why it is important. In *Paper presented at the british educational research association annual conference*. Exeter.

Cohen, L., Manion, L., & Morrison, K. (2012). *Research methods in education*. London, England: Routledge.

Cohoon, J. M., & Aspray, W. (2006). *Women and information technology: Research on underrepresentation* (Vol. 1). MIT Press.

Colburn, T., & Shute, G. (2007). Abstraction in computer science. *Minds and Machines*, *17*(2), 169–184.

Colucci-Gray, L., Trowsdale, J., Cooke, C. F., Davies, R., Burnard, P., & Gray, D. S. (2017). Reviewing the potential and challenges of developing STEAM education through creative pedagogies for 21st learning: How can school curricula be broadened towards a more responsive, dynamic, and inclusive form of education? *British Educational Research Association*. Retrieved from https://www.bera.ac.uk/project/reviewing-the-potential-and-challenges-of-developing-steam-education-2

Constantino, J. N., & Todd, R. D. (2003). Autistic traits in the general population: A twin study. *Archives of General Psychiatry*, *60*(5), 524–530.

Conti, R., Coon, H., & Amabile, T. M. (1996). Evidence to support the componential model of creativity: Secondary analyses of three studies. *Creativity Research Journal*, *9*(4), 385–389.

Cooper, S., Dann, W., & Pausch, R. (2000). Alice: A 3-D tool for introductory programming concepts. In *Journal of computing sciences in colleges* (Vol. 15, pp. 107–116). Consortium for Computing Sciences in Colleges.

Cooper, S., Wang, K., Israni, M., & Sorby, S. (2015). Spatial skills training in introductory computing. In *Proceedings of the eleventh annual international conference on international computing education research* (pp. 13–20). ACM.

Corbin, J., & Strauss, A. (2008). *Basics of qualitative research* (3rd ed.). London: SAGE.

Craft, A., & Jeffrey, B. (2008). Creativity and performativity in teaching and learning: Tensions, dilemmas, constraints, accommodations and synthesis. *British Educational Research Journal*, *34*(5), 577–584.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches*. London, England: SAGE.

Crombie, G., Abarbanel, T., & Trinneer, A. (2002). All-female classes in high school computer science: Positive effects in three years of data. *Journal of Educational Computing Research*, *27*(4), 385–409.

Crookall, D. (1988). Computerized simulation: An overview. *Social Science Computer Review*, *6*(1), 1–11.

Csikszentmihalyi, M. (1999). Implications of a systems perspective for the study of creativity. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 313–335). UK: Cambridge University Press.

Csikszentmihalyi, M. (2013). Creativity: The psychology of discovery and invention. New York: Harper Perennial.

Curzon, P., Dorling, M., Ng, T., Selby, C., & Woollard, J. (2014). *Developing computational thinking in the classroom: A framework*. UK: Computing At School.

Czerkawski, B. C., & Lyman, E. W. (2015). Exploring issues about computational thinking in higher education. *TechTrends*, *59*(2), 57–65.

Dangelmaier, H. T., & Hermann, C. (2017). Getting girls in STEM & the dangers of forgetting that science is art - someone made it up. *The STEAM Journal*, *3*(1), 10.

Dann, W. P., Cooper, S., & Pausch, R. (2008). *Learning to program with Alice*. Prentice Hall Press.

DCLG. (2015). English indices of deprivation 2015. London, England. Retrieved from https://www.gov.uk/government/statistics/english-indices-of-deprivation-2015

DeMarco, T., & Lister, T. (1985). Programmer performance and the effects of the workplace. In *Proceedings of the 8th international conference on software engineering* (pp. 268–272). IEEE Computer Society Press.

Denning, P. J., & Tedre, M. (2019). *Computational thinking*. London, England: MIT Press.

DfE. (2013). National curriculum in England: Computing programmes of study. Retrieved from https://www.gov.uk/government/publications/national-curriculum-in-england-computing-programmes-of-study

DfE. (2014). Secondary accountability measures (including progress 8 and attainment 8). Retrieved from https://www.gov.uk/government/publications/progress-8-school-performance-measure

DfE. (2015a). Further additional GCSE and a level subject content consultation. London, England. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/473195/Further_additional_GCSE_and_A_level_subject_content_consultation.pdf

DfE. (2015b). Further additional GCSE and a level subject content consultation. London, England. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/473195/Further_additional_GCSE_and_A_level_subject_content_consultation.pdf

DfE. (2015c). The national pupil database. User guide. London, England. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/472700/NPD_user_guide.pdf

DfE. (2016a). All edubase data.csv. London, England. Retrieved from http://www.education.gov.uk/edubase/home.xhtml

DfE. (2016b). Pupil premium: Funding and accountability for schools. Retrieved from https://www.gov.uk/guidance/pupil-premium-information-for-schools-and-alternative-provision-settings

DfE. (2019a). Search for schools and colleges to compare. London, England. Retrieved from https://www.compare-school-performance.service.gov.uk/

DfE. (2019b). Statistics: School workforce. Retrieved from https://www.gov.uk/government/collections/statistics-school-workforce

DfES. (2007). *Gender and education: The evidence on pupils in england*. London, England: Department for Education and Skills. Retrieved from http://webarchive.nationalarchives.gov.uk/20090108131527/http://www.dcsf.gov.uk/research/data/uploadfiles/RTP01-07.pdf

Dijkstra, E. W. (1982). *On the role of scientific thought* (pp. 60–66). New York, USA: Springer.

Djumalieva, J., & Sleeman, C. (2018). Which digital skills do you really need? *Nesta*. Retrieved from https://www.nesta.org.uk/report/which-digital-skills-do-you-really-need

Drabowicz, T. (2014). Gender and digital usage inequality among adolescents: A comparative study of 39 countries. *Computers & Education*, *74*, 98–111.

Edge. (2008). Skills Shortages in the UK Economy. Retrieved from http://www.edge.co.uk/sites/default/files/documents/final_skills_shortage_bulletin_web_2.pdf

Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of Advanced Nursing*, *62*(1), 107–115.

Ericsson, K. A., & Charness, N. (1994). Expert performance: Its structure and acquisition. *American Psychologist*, *49*(8), 725.

Estes, Z., & Ward, T. B. (2002). The emergence of novel attributes in concept modification. *Creativity Research Journal*, *14*(2), 149–156.

Field, A., Miles, J., & Field, Z. (2012). Discovering statistics using R. London, England: SAGE.

Fincher, S., Robins, A., Baker, B., Box, I., Cutts, Q., Raadt, M. de, … others. (2006). Predictors of success in a first programming course. In *Proceedings of the 8th Australasian Conference on Computing Education* (pp. 189–196). Australian Computer Society, Inc.

Florida, R. (2002). *The rise of the creative class* (Vol. 9). New York: Basic Books.

Francis, B., & Skelton, C. (2005). *Reassessing gender and achievement: Questioning contemporary key debates*. London, England: Routledge.

Fulton, J., & Paton, E. (2016). The systems model of creativity. In P. McIntyre, J. Fulton, & E. Paton (Eds.), *The creative system in action: Understanding cultural production and practice* (pp. 27–43). Basingstoke, England: Palgrave MacMillan.

Furber, S. (2012). Shut down or restart? The way forward for computing in uk schools. *The Royal Society*. Retrieved from https://royalsociety.org/topics-policy/projects/computing-in-schools/report/

Futschek, G. (2006). Algorithmic thinking: The key for understanding computer science. In *International conference on informatics in secondary schools-evolution and perspectives* (pp. 159–168). Springer.

Gardner, H. (1993). *Frames of mind: The theory of multiple intelligences* (2nd ed.). London, England: Harper Collins.

Garneli, V., Giannakos, M. N., & Chorianopoulos, K. (2015). Computing education in k-12 schools: A review of the literature. In *Global engineering education conference (educon), 2015 ieee* (pp. 543–551). IEEE.

George, M. (2019). Third of school computers 'ineffective'. TES. Retrieved from https://www.tes.com/news/exclusive-third-school-computers-ineffective

Gibson, J. J. (2014). *The ecological approach to visual perception: Classic edition*. Psychology Press.

Gilje, Ø. (2011). Working in tandem with editing tools: Iterative meaning-making in filmmaking practices. *Visual Communication*, *10*(1), 45–62.

Google. (2015). Exploring Computational Thinking. Retrieved from https://edu.google.com/resources/pro grams/exploring-computational-thinking/#!ct-overview%0A

Gould, J., & Ashton-Smith, J. (2011). Missed diagnosis or misdiagnosis? Girls and women on the autism spectrum. *Good Autism Practice (GAP)*, *12*(1), 34–41.

Gove, M. (2012). Michael Gove speech at the BETT Show 2012. London, England: Department for Education. Retrieved from https://www.gov.uk/government/speeches/michael-gove-speech-at-the-bett-show-2012

Green, R. (2017). Unmaintainable code : Naming. Retrieved from http://www.mindprod.com/jgloss/unmain.html

Greenberg, I., Kumar, D., & Xu, D. (2012). Creative coding and visual portfolios for cs1. In *Proceedings of the 43rd ACM technical symposium on Computer Science Education* (pp. 247–252). ACM.

Grigorenko, E. L., Jarvin, L., Tan, M., & Sternberg, R. J. (2008). Something new in the garden: Assessing creativity in academic domains. *Psychology Science*, *50*(2), 295.

Guzdial, M. (2018). Teaching two programming languages in the first CS course. *Communications of the ACM Blog*. Retrieved from https://cacm.acm.org/blogs/blog-cacm/228006-teaching-two-programming-languages-in-the-first-cs-course/fulltext

Hackerrank. (2018). Developer skills report. Retrieved from https://research.hackerrank.com/developer-skills/2018/

Hague, C. (2010). It's not chalk and talk anymore: School approaches to developing students' digital literacy. *Future Lab*. Retrieved from https://www.nfer.ac.uk/publications/FUTL09/FUTL09.pdf

Haines, T. S. F. (2017). 3Dcamp survival guide Summer 2017.

Haines, T. S. F., & Kemp, P. E. J. (2017). 3Dcamp 2018 intro presentation.

Hammersley, M., & Atkinson, P. (2007). *Ethnography: Principles in practice* (3rd ed.). London: Routledge.

Hammond, M. (2010). What is an affordance and can it help us understand the use of ict in education? *Education and Information Technologies*, *15*(3), 205–217.

Harel, I. (2001). Building software beats using it. Retrieved. Retrieved from https://web.archive.org/web/20010301144332/http://www.mamamedia.com/areas/grownups/new/21_learning/building_software.html

Hart, M., Early, J. P., & Brylow, D. (2008). A novel approach to K-12 CS education: Linking mathematics and computer science. In *ACM sigcse bulletin* (Vol. 40, pp. 286–290). ACM.

Helsper, E. J., & Eynon, R. (2010). Digital natives: Where is the evidence? *British Educational Research Journal*, *36*(3), 503–520.

Henley, D. (2012). Cultural education in England. *Department for Culture, Media and Sport and the Department for Education.* Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/260726/Cultural_Education_report.pdf

Higgins, S., Katsipataki, M., Villanueva-Aguilera, A., Coleman, R., Henderson, P., Major, L., … Mason, D. (2016). The Sutton Trust - Education Endowment Foundation Teaching and Learning Toolkit. Education Endowment Foundation.

Hobbs, G., & Vignoles, A. (2010). Is children's free school meal 'eligibility' a good proxy for family income? *British Educational Research Journal*, *36*(4), 673–690. doi:10.1080/01411920903083111

Hu, C. (2011). Computational thinking: What it might mean and what we might do about it. In *Proceedings of the 16th annual joint conference on innovation and technology in computer science education* (pp. 223–227). ACM.

Huang, C. (2013). Gender differences in academic self-efficacy: A meta-analysis. *European Journal of Psychology of Education*, *28*(1), 1–35.

Hugill, A., & Yang, H. (2013). The creative turn: New challenges for computing. *International Journal of Creative Computing*, *1*(1), 4–19.

Hur, J. W., Andrzejewski, C. E., & Marghitu, D. (2017). Girls and computer science: Experiences, perceptions, and career aspirations. *Computer Science Education*, *27*(2), 100–120.

Informatics Europe. (2014). 2014 best practices in education award. Retrieved from http://www.informatics-europe.org/awards/education-award/2014.html

ISTE, & CSTA. (2011). Computational thinking in k–12 education leadership toolkit. Retrieved from https://id.iste.org/docs/ct-documents/ct-leadershipt-toolkit.pdf

Ito, M., Baumer, S., Bittanti, M., Cody, R., Stephenson, B. H., Horst, H. A., … others. (2009). *Hanging out, messing around, and geeking out: Kids living and learning with new media.* MIT Press.

Jackson, F. (1982). Epiphenomenal qualia. *Philosophical Quarterly*, *32*, 127–136.

JCQ. (2017a). GCE results summer 2017. Retrieved from https://www.jcq.org.uk/examination-results/a-levels/2017/main-results-tables

JCQ. (2017b). GCSE (full course): Outcomes for all grade sets and age breakdowns for uk candidates.

Retrieved from https://www.jcq.org.uk/examination-results/gcses/2017/gcse-full-course-results-summer-2017

Joel, W., Aoki, M., Pollak, J., DeYoung, J., Ursyn, A., & Chang, W.-C. (2018). Massive collaborative animation projects: Changing paradigms in animation education. In *ACM siggraph 2018 educator's forum* (p. 3). ACM.

Joint Council for Qualifications. (2016). GCSE and entry level certificate results summer 2016. Retrieved from http://www.jcq.org.uk/examination-results/gcses/2016/gcse-and-entry-level-certificate-results-summer-2017

Joint Council for Qualifications. (2018a). GCSE and entry level certificate results summer 2018. Retrieved from https://www.jcq.org.uk/examination-results/a-levels/2018/main-results-tables

Joint Council for Qualifications. (2018b). GCSE and entry level certificate results summer 2018. Retrieved from https://www.jcq.org.uk/examination-results/gcses/2018/main-results-tables

Jörg, S., Leonard, A. E., Babu, S., Gundersen, K., Parmar, D., Boggs, K., & Daily, S. B. (2014). Character animation and embodiment in teaching computational thinking. In *ACM siggraph 2014 posters* (p. 4). ACM.

Karasavvvidis, I. (2019). Students' use of digital video effects in multimodal compositions: An exploratory study. *Journal of Visual Literacy*, *38*(3), 221–244. doi:10.1080/1051144X.2019.1611697

Kaufman, J. C., & Beghetto, R. A. (2009). Beyond big and little: The four c model of creativity. *Review of General Psychology*, *13*(1), 1.

Kay, A. (1990). User interface: A personal view. Retrieved from http://worrydream.com/refs/Kay%20-%20User%20Interface,%20a%20Personal%20View.pdf

Kemp, P. E. J. (2014a). 3D animation in schools. *NAACE Advancing Education*, (2). Retrieved from https://www.naace.co.uk/publications/advancing-education-summer-2014/

Kemp, P. E. J. (2014b). Computing in the national curriculum: A guide for secondary teachers. London, England: NAACE, Computing at School. Retrieved from http://community.computingatschool.org.uk/files/3383/original.pdf

Kemp, P. E. J. (2016). *Blender for school aged students.* Retrieved from https://docs.google.com/presentation/d/1OeU4tkigTo3oDWVZK86tMTUCH7QJSKtzmT_thOSVMXQ/edit#slide=id.p

Kemp, P. E. J. (2017). The Royal Society Computing Project - KS4 NPD data on gender, pupil premium, BAME, EAL and course choices in computing. *The Royal Society.*

Kemp, P. E. J., & Berry, M. G. (2019). The Roehampton Annual Computing Education Report. London, England: University of Roehampton. Retrieved from https://www.bcs.org/more/bcs-academy-of-computing/the-roehampton-annual-computing-education-report

Kemp, P. E. J., Berry, M. G., & Wong, B. (2018). The Roehampton Annual Computing Education Report. London, England: University of Roehampton.

Kemp, P. E. J., Wong, B., & Berry, M. G. (2016). The Roehampton Annual Computing Education Report: Data from 2015.

Kennewell, S. (2001). Using affordances and constraints to evaluate the use of information and communications technology in teaching and learning. *Journal of Information Techology for Teacher Education*, *10*(1-2), 101–116.

Kong, S.-C., Abelson, H., & Lai, M. (2019). Introduction to computational thinking education. In *Computational thinking education* (pp. 1–10). Springer. Retrieved from https://link.springer.com/content/pdf/10.1007/978-981-13-6528-7.pdf

Kozbelt, A., Beghetto, R. A., & Runco, M. A. (2010). Theories of creativity. In J. C. Kaufman & R. J. Sternberg (Eds.), *The Cambridge Handbook of Creativity* (1st ed., pp. 20–47). UK: Cambridge University Press.

Kress, G. R. (2009). *Multimodality: A social semiotic approach to contemporary communication.* Abington, UK: Routledge.

Kress, G. R., & Van Leeuwen, T. (2006). *Reading images: The grammar of visual design* (2nd ed.). Abington, UK: Routledge.

Kress, G. R., & Van Leeuwen, T. V. (2001). Multimodal discourse: The modes and media of contemporary communication.

Kretchmar, J. (2015). Seymour Papert and constructionism. *Research Starters: Education (Online Edition).*

Kuhn, T. S. (2012). *The structure of scientific revolutions.* University of Chicago press.

Lachney, M., Babbitt, W., & Eglash, R. (2016). Software design in the ”construction genre” of learning technology: Content aware versus content agnostic. *Computational Culture*, *5*.

Lakhan, S. E., & Jhunjhunwala, K. (2008). Open source software in education. *Educause Quarterly*, *31*(2), 32.

Lasen, M. (2010). Education and career pathways in information communication technology: What are schoolgirls saying? *Computers & Education*, *54*(4), 1117–1126.

Lasseter, J. (1987). Principles of traditional animation applied to 3D computer animation. In *ACM siggraph computer graphics* (Vol. 21, pp. 35–44). ACM.

Lau, W. W., & Yuen, A. H. (2009). Exploring the effects of gender and learning styles on computer programming performance: Implications for programming pedagogy. *British Journal of Educational Technology*, *40*(4), 696–712.

Leavis, F. R. (1962). *Two cultures? The significance of CP Snow.* UK: Cambridge University Press.

Leavis, F. R. (1972). *Nor shall my sword: Discourses on pluralism, compassion and social hope.* London, England: Chatto & Windus.

L'Heureux, J., Boisvert, D., Cohen, R., & Sanghera, K. (2012). IT problem solving: An implementation of computational thinking in information technology. In *Proceedings of the 13th annual conference on information technology education* (pp. 183–188). ACM.

Lin, L., Parmar, D., Babu, S. V., Leonard, A. E., Daily, S. B., & Jörg, S. (2017). How character customization affects learning in computational thinking. In *Proceedings of the ACM Symposium on Applied Perception* (p. 1). ACM.

Lincoln, Y. S., & Guba, E. G. (1985). Naturalistic inquiry. Thousand Oaks, CA: Sage.

Lishinski, A., Yadav, A., Good, J., & Enbody, R. J. (2016). Learning to program: Gender differences and interactive effects of students' motivation, goals, and self-efficacy on performance. In *Proceedings of the 12th annual international acm conference on international computing education research (icer '16)* (pp. 211–220).

Livingstone, I., & Hope, A. (2011). Next gen: Transforming the uk into the world's leading talent hub for the video games and visual effects industries. *National Endowment for Science, Technology and the Arts (Nesta).*

Long, I., Robert, L., & Davis, S. S. (2017). Using STEAM to Increase Engagement and Literacy Across Disciplines. *The STEAM Journal*, *3*(1), 7.

Lubart, T. (2010). Cross-cultural perspectives on creativity. In J. C. Kaufman & R. J. Sternberg (Eds.), *The Cambridge Handbook of Creativity* (1st ed.). UK: Cambridge University Press.

MAC. (2015). Partial review of the Shortage Occupation Lists for the UK and for Scotland. London, England: Migration Advisory Committee. Retrieved from https://assets.publishing.service.gov.uk/gover nment/uploads/system/uploads/attachment_data/file/406775/Partial_review_of_the_SOL_for_UK_and_Scotland_Report.pdf

Maeda, J. (2013). STEM + Art = STEAM. *The STEAM Journal*, *1*(1), 34.

Maloney, J., Resnick, M., Rusk, N., Silverman, B., & Eastmond, E. (2010). The scratch programming language and environment. *ACM Transactions on Computing Education (TOCE)*, *10*(4), 16.

Manovich, L. (2013). *Software takes command* (Vol. 5). A&C Black.

Manovich, L., Malina, R. F., & Cubitt, S. (2001). *The language of new media.* USA: MIT press.

Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). STEM: Country comparisons: International comparisons of science, technology, engineering and mathematics (STEM) education. Final report. Retrieved from https://acola.org.au/wp/PDF/SAF02Consultants/SAF02_STEM_%20FINAL.pdf

Margolis, J., & Fisher, A. (2003). *Unlocking the clubhouse: Women in computing.* MIT Press.

May, T. (2003). *Social research: Issues, methods and process* (3rd ed.). Maidenhead: Open University Press.

Mayer, R. E. (1999). Fifty years of creativity research. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 449–460). Cambridge University Press.

McGrenere, J., & Ho, W. (2000). Affordances: Clarifying and evolving a concept. In *Graphics interface* (Vol. 2000, pp. 179–186).

Mednick, S. (1962). The associative basis of the creative process. *Psychological Review*, *69*(3), 220.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook.* UK: SAGE.

Moller, F., & Crick, T. (2018). A university-based model for supporting computer science curriculum reform. *Journal of Computers in Education*, *5*(4), 415–434.

Myers, B. (2018). Women and minorities in tech, by the numbers. Wired. Retrieved from https://www.wired.com/story/computer-science-graduates-diversity/

Nelson, T. H. (1965). Complex information processing: A file structure for the complex, the changing and the indeterminate. In *Proceedings of the 1965 20th national conference* (pp. 84–100). ACM.

Newman, T. (2009). Consequences of a digital literacy review: Moving from terminology to action. Retrieved from https://www.slideshare.net/TabethaNewman/digital-literacy-literature-review-from-terminology-to-action

Norman, D. A. (1988). The psychology of everyday things.(The design of everyday things). Basic Books.

NRC. (2010). *Report of a workshop on the scope and nature of computational thinking.* National Research Council, National Academies Press.

O'Connor, K. (2018). We need to talk about skills - a skills analysis of the uk animation industry. Animation UK. Retrieved from http://www.ukscreenalliance.co.uk/news/article/5344

OCR. (2012). GCSE computing - j275 (from 2012). Retrieved from http://www.ocr.org.uk/qualifications/gcse-computing-j275-from-2012/

OCR. (2018). Media studies. Retrieved from https://www.ocr.org.uk/Images/316659-specification-accredited-gcse-media-studies-j200.pdf

Ofcom. (2015). Adult's media use and attitudes. Retrieved from http://www.ofcom.org.uk/___data/assets/pdf_file/0014/82112/2015_adults_media_use_and_attitudes_report.pdf

Ofcom. (2017). Children and parents: Media use and attitudes report. Retrieved from https://www.ofcom.org.uk/___data/assets/pdf_file/0020/108182/children-parents-media-use-attitudes-2017.pdf

Office of Qualifications and Examinations Regulation. (2015). Comparability of Different GCSE and A Level Subjects in England: An Introduction. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/
comparability-of-different-gcse-and-a-level-subjects-in-england-an-introduction.pdf

Ofqual. (2016). Can different GCSE and A level subjects be compared accurately? Retrieved from https://www.gov.uk/government/news/can-different-gcse-and-a-level-subjects-be-compared-accurately

Orr, G. (2009). Computational thinking through programming and algorithmic art. In *SIGGRAPH 2009: Talks* (p. 31). ACM.

Osborn, A. F. (1963). *Applied imagination* (3rd ed.). New York: Scribner.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas.* New York: Basic Books.

Papert, S., & Harel, I. (1991). Situating constructionism. In S. Papert & I. Harel (Eds.), *Constructionism: Research reports and essays 1985-1990* (pp. 1–11). New Jersey: Ablex.

Pearce, L. (1994). *Reading dialogics.* London, England: Arnold Hodder.

Perens, B., & others. (1999). The open source definition. *Open Sources: Voices from the Open Source Revolution*, *1*, 171–188. Retrieved from https://www.oreilly.com/openbook/opensources/book/perens.html

Perković, L., Settle, A., Hwang, S., & Jones, J. (2010). A framework for computational thinking across the curriculum. In *Proceedings of the fifteenth annual conference on innovation and technology in computer* *science education* (pp. 123–127). ACM.

Prensky, M. (2001). Digital natives, digital immigrants part 1. *On the Horizon*, *9*(5), 1–6.

Prieur, A., & Savage, M. (2013). Emerging forms of cultural capital. *European Societies*, *15*(2), 246–267.

Punch, K. F. (2009). *Introduction to research methods in education*. London, England: SAGE.

QCA. (2007). ICT: Programme of study for key stage 3 and attainment targets. London, England: Qualifications; Curriculum Authority.

Quigley, C. (2017). Working towards a better gender balance in coderdojo scotland clubs. Retrieved from http://coderdojoscotland.com/reports/scotgov-gender-balance-2017/Gender-Balance-Analysis-V1.0-Final.pdf

Quinlan, O. (2015). Young digital makers. *London: Nesta*. Retrieved from https://media.nesta.org.uk/documents/youngdigmakers.pdf

Reilly, D., Neumann, D. L., & Andrews, G. (2017). Gender differences in spatial ability: Implications for STEM education and approaches to reducing the gender gap for parents and educators. In *Visual-spatial ability in stem education* (pp. 195–224). Springer.

Resnick, M., Maloney, J., Monroy-Hernández, A., Rusk, N., Eastmond, E., Brennan, K., … others. (2009). Scratch: Programming for all. *Communications of the ACM*, *52*(11), 60–67.

Richards, R. (2010). Everyday creativity: Process and way of life - four key issues. In J. C. Kaufman & R. J. Sternberg (Eds.), *The Cambridge Handbook of Creativity* (1st ed., pp. 189–215). UK: Cambridge University Press.

Richardson, M., Abraham, C., & Bond, R. (2012). Psychological correlates of university students' academic performance: A systematic review and meta-analysis. *Psychological Bulletin*, *138*(2), 353.

Rim, H., & Lee, G. (2012). An education effects through 3D animation implementation using educational programming language. *Journal of Digital Contents Society*, *13*(3), 459–467.

Robelen, E. W. (2011). STEAM: Experts make case for adding arts to STEM. *Education Week*, *31*(13), 8.

Robinson, K. (2011). *Out of our minds: Learning to be creative* (2nd ed.). Chichester, UK: Capstone Wiley.

Roller, M. A. (2015). *A consensus on the definition and knowledge base for computer graphics* (PhD thesis). Purdue University. Retrieved from https://docs.lib.purdue.edu/open_access_dissertations/698/

Royal Society. (2017). After the reboot: computing education in UK schools. *The Royal Society*.

Rubin, H. J., & Rubin, I. S. (2005). *Qualitative interviewing: The art of hearing data* (2nd ed.). London: SAGE.

Rudd, T. (2013). The ideological construction opf a new form of digital exclusion: Computer science as latin or total deus ex machina? *The Journal for Critical Education Policy Studies*, *11*(3), 287–305.

Runco, M. A. (2003). Education for creative potential. *Scandinavian Journal of Educational Research*, *47*(3), 317–324.

Russell Group. (2016). Informed choices, a Russell Group guide to making decisions about post-16 education. Retrieved from http://www.russellgroup.ac.uk/media/5320/informedchoices.pdf

Sadler, J., Shluzas, L., & Blikstein, P. (2017). Building blocks in creative computing: Modularity increases the probability of prototyping novel ideas. *International Journal of Design Creativity and Innovation*, *5*(3-4), 168–184.

Sanders, M. E. (2008). STEM, stem education, stemmania. Retrieved from https://vtechworks.lib.vt.edu/bitstream/handle/10919/51616/STEMmania.pdf?sequence

Scantlebury, K., & Baker, D. (2013). Gender issues in science education research: Remembering where the difference lies. In S. K. Abell, K. Appleton, & D. L. Hanuscin (Eds.), *Handbook of research on science education* (pp. 257–286). Oxford: Routledge.

Schell, B. H., & Melnychuk, J. (2011). Female and male hacker conferences attendees: Their autism-spectrum quotient (aq) scores and self-reported adulthood experiences. In *Corporate hacking and technology-driven crime: Social dynamics and implications* (pp. 144–169). IGI Global.

Schmitt, D. P., Long, A. E., McPhearson, A., O'brien, K., Remmert, B., & Shah, S. H. (2017). Personality and gender differences in global perspective. *International Journal of Psychology*, *52*, 45–56.

Schunk, D. H. (1991). Self-efficacy and academic motivation. *Educational Psychologist*, *26*(3-4), 207–231. doi:10.1080/00461520.1991.9653133

Schunk, D. H., & Pajares, F. (2002). The development of academic self-efficacy. In W. J. S. & E. J. S. (Eds.), *Development of achievement motivation* (pp. 15–31). San Diego: Academic Press.

Sefton-Green, J. (1999). *Young people, creativity and new technologies: The challenge of digital arts.* London, England: Routledge.

Sefton-Green, J. (2000). *Introduction: Evaluating creativity.* (J. Sefton-Green & R. Sinker, Eds.). Abington, England: Routledge.

Sefton-Green, J. (2005). Timelines, timeframes and special effects: Software and creative media production. *Education, Communication & Information*, *5*(1), 99–110.

Sefton-Green, J. (2013). Mapping digital makers: A review exploring everyday creativity, learning lives and the digital. *Nominet Trust*. Retrieved from http://www.julianseftongreen.net/wp-content/uploads/2013/03/NT-SoA-6-FINAL.pdf

Sefton-Green, J. (2014). *NextGen report: Have its recommendations been implemented?* Retrieved from https://web.archive.org/web/20150821224944/http://progressionintocreativecareers.co.uk/2014/01/24/nextgen-report-have-its-recommendations-been-implemented/%0A

Sefton-Green, J., & Brown, L. (2014). Mapping learner progression into digital creativity: Catalysts & disconnects. *Nominet Trust*. Retrieved from https://socialtechtrust.org/wp-content/uploads/2017/11/Mapping-learner-progression-into-digital-creativity-FINAL.pdf

Sefton-Green, J., Thomson, P., Jones, K., & Bresler, L. (2011). *The Routledge international handbook of creative learning*. London, England: Routledge.

Selby, C., & Woollard, J. (2013). *Computational thinking: The developing definition*. University of Southampton (E-prints).

Seltzer, K., & Bentley, T. (1999). *The creative age: Knowledge and skills for the new economy*. Demos. Retrieved from https://www.demos.co.uk/files/theCreativeage.pdf

Selwyn, N. (2009). The digital native–myth and reality. In *Aslib proceedings* (Vol. 61, pp. 364–379). Emerald Group Publishing Limited.

Simonton, D. K. (1988). *Scientific genius: A psychology of science*. UK: Cambridge University Press.

Simonton, D. K. (2003). Scientific creativity as constrained stochastic behavior: The integration of product, person, and process perspectives. *Psychological Bulletin*, *129*(4), 475.

Snow, C. P. (1959). *The two cultures*. UK: Cambridge University Press.

Soegaard, M. (2015). Affordances. *The Interaction Design Foundation*. Retrieved from https://www.interaction-design.org/literature/book/the-glossary-of-human-computer-interaction/affordances

Spencer, L., Ritchie, J., & O'Connor, W. (2003). Analysis: Practices, principles and processes. In *Qualitative research practice: A guide for social science students and researchers* (pp. 199–218). London: SAGE.

Steers, J. (2013). Creativity in schools: Delusions, realities and challenges. In K. Thomas & J. Chan (Eds.), *Handbook of research on creativity*. Edward Elgar Publishing.

Steers, J. (2014). Reforming the school curriculum and assessment in england to match the best in the world–a cautionary tale. *International Journal of Art & Design Education*, *33*(1), 6–18.

STEM Learning. (2018). A world-leading computing education for every young person. Retrieved from https://www.stem.org.uk/news-and-views/news/world-leading-computing-education-every-young-person

Sternberg, R. J., & Kaufman, J. C. (2010). Constraints on creativity: Obvious and not so obvious. In J. C. Kaufman & R. J. Sternberg (Eds.), *The Cambridge Handbook of Creativity* (1st ed., pp. 467–482). UK: Cambridge University Press.

Steup, M. (2018). Epistemology. In E. N. Zalta (Ed.), *The stanford encyclopedia of philosophy* (Winter 2018.). https://plato.stanford.edu/archives/win2018/entries/epistemology/; Metaphysics Research Lab, Stanford University.

Stoet, G., & Geary, D. C. (2018). The gender-equality paradox in science, technology, engineering, and mathematics education. *Psychological Science*, *29*(3). Retrieved from https://doi.org/10.1177/0956797617741719

Stoilescu, D., & Egodawatte, G. (2010). Gender differences in the use of computers, programming, and peer interactions in computer science classrooms. *Computer Science Education*, *20*(4), 283–300.

Tarkovsky, A. (1989). *Sculpting in time: Reflections on the cinema.* (K. Hunter-Blair, Trans.). University of Texas Press.

Tech Nation. (2019). UK tech on the global stage. Tech Nation. Retrieved from https://technation.io/report2019/

Tedre, M., & Denning, P. J. (2016). The long quest for computational thinking. In *Proceedings of the 16th koli calling international conference on computing education research* (pp. 120–129). ACM.

Thomas, F., Johnston, O., & Thomas, F. (1995). *The illusion of life: Disney animation.* New York: Hyperion.

Thompson, L. (2013). *Creative conspiracy: The new rules of breakthrough collaboration.* Harvard Business Review Press.

Thomson, P., Hall, C., Jones, K., & Sefton-Green, J. (2012). The signature pedagogies project: Final report. *Creativity, Culture and Education.* Retrieved from https://www.creativitycultureeducation.org/publication/the-signature-pedagogies-project/

Timko, Nick. (2011). Is minecraft turing-complete? Retrieved from https://gaming.stackexchange.com/q uestions/20219/is-minecraft-turing-complete

Turing, A. M. (1937). On computable numbers, with an application to the entscheidungsproblem. *Proceedings of the London Mathematical Society*, *2*(1), 230–265.

Varma, R. (2010). Why so few women enroll in computing? Gender and ethnic differences in students' perception. *Computer Science Education*, *20*(4), 301–316.

Vazquez, P. (2019, January 28). Youtube. Retrieved from https://youtu.be/VhUTDbvoEUQ?t=314

Vekiri, I. (2013). Information science instruction and changes in girls' and boy's expectancy and value beliefs: In search of gender-equitable pedagogical practices. *Computers & Education*, *64*, 104–115.

Vitores, A., & Gil-Juárez, A. (2016). The trouble with 'women in computing': A critical examination of the deployment of research on the gender gap in computer science. *Journal of Gender Studies*, *25*(6), 666–680. doi:10.1080/09589236.2015.1087309

Voyer, D., & Voyer, S. D. (2014). Gender differences in scholastic achievement: A meta-analysis. *Psychological Bulletin*, *140*(4), 1174.

Vygotsky, L. S. (2004). Imagination and creativity in childhood. *Journal of Russian & East European Psychology*, *42*(1), 7–97.

Wagner, I. (2016). Gender and performance in computer science. *ACM Transactions on Computing Education (TOCE)*, *16*(3), 11.

Wang, M.-T., Eccles, J. S., & Kenny, S. (2013). Not lack of ability but more choice: Individual and gender differences in choice of careers in science, technology, engineering, and mathematics. *Psychological Science*, *24*(5), 770–775.

Webb, M., Davis, N., Bell, T., Katz, Y. J., Reynolds, N., Chambers, D. P., & Sysło, M. M. (2017). Computer science in k-12 school curricula of the 2lst century: Why, what and when? *Education and Information Technologies*, *22*(2), 445–468.

Weedon, C. (1987). Feminist practice and poststructuralist theory. Oxford, UK: Basil Blackwell.

Whitehurst, A. (2018). The visual effects pipeline. Retrieved from http://www.andrew-whitehurst.net/pipeline.html

Wiedenbeck, S., Labelle, D., & Kain, V. N. (2004). Factors affecting course outcomes in introductory programming. In *16th annual workshop of the psychology of programming interest group* (pp. 97–109).

Wilson, B. C. (2002). A study of factors promoting success in computer science including gender differences. *Computer Science Education*, *12*(1-2), 141–164. doi:10.1076/csed.12.1.141.8211

Wilson, B. C., & Shrock, S. (2001). Contributing to success in an introductory computer science course: A study of twelve factors. In *ACM sigcse bulletin* (Vol. 33, pp. 184–188). ACM.

Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, *49*(3), 33–35.

Wing, J. M. (2008). Computational thinking and thinking about computing. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *366*(1881), 3717–3725.

Wing, J. M. (2011). Research notebook: Computational thinking—what and why? *The Link Magazine, Spring*. Carnegie Mellon University, Pittsburgh.

Wong, B. (2016a). 'I'm good, but not that good': Digitally-skilled young people's identity in computing. *Computer Science Education*, *26*(4), 299–317. doi:10.1080/08993408.2017.1292604

Wong, B. (2016b). *Science education, career aspirations and minority ethnic students*. Palgrave MacMillan.

Wong, B., & Kemp, P. E. J. (2018). Technical boys and creative girls: The career aspirations of digitally skilled youths. *Cambridge Journal of Education*, *48*(3), 301–316. doi:10.1080/0305764X.2017.1325443

Worth, J., & De Lazzari, G. (2017). Teacher retention and turnover research. Research update 1: Teacher retention by subject. Slough: NFER.

Young, M. (2007). What are schools for? *Educação & Sociedade*, *28*(101), 1287–1302.

Young, M. (2008). From constructivism to realism in the sociology of the curriculum. *Review of Research in Education*, *32*(1), 1–28.

10 Appendix

<u>Interview schedule</u>

<u>Interviews with directors and producers</u>

[Introduce participants that the purpose of study is to seek for their views and opinions around their creation of 3D animated shorts and the skills/attributes required to get into the VFX/Animation industry, so there are no right or wrong answers. Their details will be confidential and they can stop anytime etc.]

Introduction [start recording]

- Can you tell me a little bit about yourself *(record gender and age; Probe: area of residence, family background/structure, school attending)*

Their role

- What was your role on the film
- What were the main challenges. (*Probe:* for team, story and technical side, especially around CT concepts of Abstraction, Automation, Decomposition, Generalisation) rendering problems and how they overcame them. Drivers. Arrays.
- What was your best achievement. Probe for story and technical side
- How did you work as a team
- **What would you do differently next time**

The film

- Describe the story of your film.
    - Was it based off anything else you had seen before
    - Who would like the film (*Probe:* audience and how they focused the film for the audience)
    - Describe the use of timing
    - Describe the use of sound
    - Describe the characters
    - How did you create the emotions
    - Was it successful

Learning pathways

- How did you get involved with 3D animation / VFX
- Why did / didn't you study this directly? Probe for parental, school and societal influences (e.g. gender, race, class, wealth).
- What skills do you need think you need to work in this industry

- What learning pathways would be best for someone wanting to get into the industry? Probe for apprenticeships / degrees / GCSEs / Vocational courses. Probe for how they justify this claim
- Is anyone in your family interested in computing? (*Probe: what software/skills*) and how advanced (and learnt from where?)
- Are your friends interested in computing? (*Probe: how many are/are not? what are they interested in? Do you learn/share ideas from each other? If so, give example*)
- Do you share/learn from other internet users about computing? (*Probe: e.g. forums, chats, blogs, websites - and what did you learn?*)
- What do you see yourself doing at university (if relevant)
- What do you see yourself doing as a career (*Probe: why*)
- What stereotypes do you think people have of those working in VFX/Animation, is it different from computer science?
- Do you think learning about VFX/animation requires a lot of money? (*Probe: where did you get your IT equipment?*) Do you think those who cannot afford computers are disadvantaged? Why?
- Are people learning blender disadvantaged?
- According to statistics, some minority ethnic groups (particularly Asians) are overrepresented in the study of Computer Science at university. Why do you think this is the case? (*What about people from your ethnic background? Is computing popular? Why/why not? Do you think your ethnic background makes it easier or harder to succeed in computing?*).
- Gender, would girls find it more appealing than computing?

Any other things you would like to discuss?

Learning pathways of digital creatives: A case study of a computing summer school

Dear Parent/Guardian,

We would like to invite your child to participate in a research project. Before you decide whether to give permission for your child to take part, it is important for you to understand why the research is being done and what participation will involve. Please take time to read the following information and if there is anything that is not clear or you would like more information on, our contact details are at the end of this information sheet.

What are we doing?
We are based in the School of Education at the University of Roehampton and we are interested in ways that students become digitally creative. We will be talking to participants in the #### summer school and we would be very grateful if you would consider allowing your child to participate. Please note that your child does not need to take part in this study in order to attend the summer school. It is entirely optional.

What will the benefits of the project be?
By taking part, your child will be making a valuable contribution to the knowledge of educational researchers and professionals. In particular, we hope the project will increase awareness of the views, experiences and skills of young people in relation to digital creativity. In particular we wish to highlight their use of 3D digital animation tools.

What will participation involve?
If your child participates, he/she will be interviewed after the summer school. The interview will take approximately 40 minutes. No preparation is required and your child is free to express any views or opinions he/she wishes.

Additionally your child will be part of a ‘studio’ at the summer school. Each studio will be tasked with making a film over the course of the 7 day summer school. Close observations of several of these studios will be made, noting interactions between students and technology, and students and other students.

Participation is voluntary and your child does not have to answer any questions that they don’t want to or to have their interactions observed and recorded. You or your child have the right to withdraw from the study at any point and do not have to give a reason for doing so. With your child’s consent, the interview will be audio recorded, and later written up. Observations will include their interactions being recorded through note taking and film. All interviews and observations will be treated as strictly confidential and will be fully anonymised. No one will be able to identify your child or their school. Data will be archived for use by other researchers only in anonymous form.

What do I do next?
If you are happy for your child to take part, please sign the enclosed consent form, and return the form by mail, or when attending the summer school. We will then arrange a suitable time after the week of the summer school for the interview to take place. If applicable, observations will happen throughout the week.

Contact Details
Peter Kemp, School of Education, University of Roehampton, SW15 5PJ, Tel: 020 8392 3583, peter.kemp@roehampton.ac.uk

PARENTAL PARTICIPANT CONSENT FORM

Title of Research Project: Learning Pathways for Digital Creativity

Brief Description of Research Project, and What Participation Involves:

This study aims to find out about the learning pathways taken by young digital creatives. We hope that by understanding their learning journeys, we will be able to provide a better computing education for many young people. By taking part in this study, we will ask your child some questions about computers, technology and around their education and backgrounds. Your child might also be observed making their 3D digital movie.

My information/contact details:

Peter Kemp, School of Education, University of Roehampton, SW15 5PJ, Tel: 020 8392 3583, peter.kemp@roehampton.ac.uk

Consent Statement:

I agree that my child (named below) can take part in this research, and am aware that he/she is free to withdraw at any point without giving a reason, although the data collected might still be used in a collated form. I understand that the information my child provides will be treated in confidence by the investigator and that his/her identity will be protected in the publication of any findings, and that data will be collected and processed in accordance with the Data Protection Act 1998 and with the University's Data Protection Policy.

Child name …………………………………   Your name ………………………………….

Signature ………………………………   Date ……………………………………

Please note: if you have a concern about any aspect of participation in this research or any other queries please raise this with the investigator or their Director of Studies. However, if you would like to contact an independent party please contact the Head of Research.

Director of Research Contact Details: Professor Vini Lander, School of Education, University of Roehampton, SW15 5PJ, Tel: 020 8392 3865, vini.lander@roehampton.ac.uk

Director of Studies: Professor Debbie Epstein, Cedar 108, Froebel College, School of Education, University of Roehampton, SW15 5PJ, Tel: 020 8392 3768, Debbie.Epstein@roehampton.ac.uk
[Please keep one copy for your reference]

Learning pathways of digital creatives: A case study of a computing summer school

Dear Student,

We would like to invite you to participate in a research project. Before you decide whether to give your permission to take part, it is important for you to understand why the research is being done and what participation will involve. Please take time to read the following information and if there is anything that is not clear or you would like more information on, our contact details are at the end of this information sheet.

What are we doing?
We are based in the School of Education at the University of Roehampton and we are interested in ways that students become digitally creative. We will be talking to participants in the #### summer school and we would be very grateful if you would participate. Please note that you do not need to take part in this study in order to attend the summer school. It is entirely optional.

What will the benefits of the project be?
By taking part, you will be making a valuable contribution to the knowledge of educational researchers and professionals. In particular, we hope the project will increase awareness of the views, experiences and skills of young people in relation to digital creativity. In particular we wish to highlight your use of 3D digital animation tools.

What will participation involve?
If you participate, you will be interviewed after the summer school. The interview will take approximately 40 minutes. No preparation is required and you are free to express any views or opinions you wish.

Additionally you will be part of a 'studio' at the summer school. Each studio will be tasked with making a film over the course of the 7 days. Close observations of several of these studios will be made, noting interactions between students and technology and students and other students.

Participation is voluntary and you do not have to answer any questions that you don't want to or to have your interactions observed and recorded. You have the right to withdraw from the study at any point and do not have to give a reason for doing so. With your consent, the interview will be audio recorded, and later written up. Observations will include their interactions being recorded through note taking and film. All interviews and observations will be treated as strictly confidential and will be fully anonymised. No one will be able to identify you or your school. Data will be archived for use by other researchers only in anonymous form.

What do I do next?
If you are happy to take part, please sign the enclosed consent form, and return the form by mail, or when attending the summer school. We will then arrange a suitable time after the week of the summer school for the interview to take place. If applicable, observations will happen throughout the week.

Contact Details Peter Kemp, School of Education, University of Roehampton, SW15 5PJ, Tel: 020 8392 3583, peter.kemp@roehampton.ac.uk

STUDENT PARTICIPANT CONSENT FORM

Title of Research Project: Learning Pathways for Digital Creativity

Brief Description of Research Project, and What Participation Involves:

This study aims to find out the learning pathways taken by young digital creatives. We hope that by understanding your learning journeys, we will be able to provide a better computing education for many young people. By taking part in this study, we will ask you some questions about computers, technology and around your education and background. You will be interviewed at a convenient time after the summer school and it should take around 40 minutes. You might also be observed making your 3D animation and details about your participation recorded.

My information/contact details:
Peter Kemp, LU019, School of Education, University of Roehampton, SW15 5PJ, Tel: 020 8392 3583, peter.kemp@roehampton.ac.uk

Consent Statement:

I agree to take part in this research, and am aware that I am free to withdraw at any point without giving a reason, although if I do so I understand that my data might still be used in a collated form. I understand that the information I provide will be treated in confidence by the investigator and that my identity will be protected in the publication of any findings, and that data will be collected and processed in accordance with the Data Protection Act 1998 and with the University's Data Protection Policy.

Name ………………………………….

Signature ………………………………   Date ……………………………………

Please note: if you have a concern about any aspect of participation in this research or any other queries please raise this with the investigator or their Director of Studies. However, if you would like to contact an independent party please contact the Head of Research.

Director of Research Contact Details: Professor Vini Lander, School of Education, University of Roehampton, SW15 5PJ, Tel: 020 8392 3865, vini.lander@roehampton.ac.uk

Director of Studies: Professor Debbie Epstein, Cedar 108, Froebel College, School of Education, University of Roehampton, SW15 5PJ, Tel: 020 8392 3768, Debbie.Epstein@roehampton.ac.uk
[Please keep one copy for your reference]

[Please keep one copy for your reference]

Media Release Form

Please complete and return with the parental consent form (this may also be scanned and emailed).

At our event we will take photographs and record audio/video for documentary and promotional purposes. Without implying any restrictions common uses are on the website, social media (e.g. Facebook, Twitter, YouTube), in leaflets, posters and for (typically short) documentaries / promotional films.

Such media may be visible worldwide (where UK law may not apply), e.g. via the website. It may be presented without time limit. We may authorise other individuals and organisations to use such media, e.g. the press.

The student's name will be included in the credit roll of the short film they create, which will then be posted publicly online. A student may choose to have their name excluded, it is up to them to tell their producer/director during the event.

I consent to my son/daughter being photographed/filmed at #### and for this media to be used as stated above. I confirm that I have legal responsibility for this individual and am entitled to give this consent.

Name: ____________________________________

Parent/Guardian of: ____________________________________ (name of student)

Address:

____

____

Postcode: __________________

Signature:_________________________ Date: ---------_________________

All information is collected in accordance with the GDPR and any subsequent legislation
Note that if you are 18 years old or older you may fill in this form yourself.

Appendix

<u>Interview schedule</u>

<u>Interviews with directors and producers</u>

[Introduce participants that the purpose of study is to seek for their views and opinions around their creation of 3D animated shorts and the skills/attributes required to get into the VFX/Animation industry, so there are no right or wrong answers. Their details will be confidential and they can stop anytime etc.]

Introduction [start recording]

- Can you tell me a little bit about yourself *(record gender and age; Probe: area of residence, family background/structure, school attending)*

Their role

- What was your role on the film
- What were the main challenges. (*Probe:* for team, story and technical side, especially around CT concepts of Abstraction, Automation, Decomposition, Generalisation) rendering problems and how they overcame them. Drivers. Arrays.
- What was your best achievement. Probe for story and technical side
- How did you work as a team
- **What would you do differently next time**

The film

- Describe the story of your film.
    - Was it based off anything else you had seen before
    - Who would like the film (*Probe:* audience and how they focused the film for the audience)
    - Describe the use of timing
    - Describe the use of sound
    - Describe the characters
    - How did you create the emotions
    - Was it successful

Learning pathways

- How did you get involved with 3D animation / VFX
- Why did / didn't you study this directly? Probe for parental, school and societal influences (e.g. gender, race, class, wealth).
- What skills do you need think you need to work in this industry

- What learning pathways would be best for someone wanting to get into the industry? Probe for apprenticeships / degrees / GCSEs / Vocational courses. Probe for how they justify this claim
- Is anyone in your family interested in computing? (*Probe: what software/skills*) and how advanced (and learnt from where?)
- Are your friends interested in computing? (*Probe: how many are/are not? what are they interested in? Do you learn/share ideas from each other? If so, give example*)
- Do you share/learn from other internet users about computing? (*Probe: e.g. forums, chats, blogs, websites - and what did you learn?*)
- What do you see yourself doing at university (if relevant)
- What do you see yourself doing as a career (*Probe: why*)
- What stereotypes do you think people have of those working in VFX/Animation, is it different from computer science?
- Do you think learning about VFX/animation requires a lot of money? (*Probe: where did you get your IT equipment?*) Do you think those who cannot afford computers are disadvantaged? Why?
- Are people learning blender disadvantaged?
- According to statistics, some minority ethnic groups (particularly Asians) are overrepresented in the study of Computer Science at university. Why do you think this is the case? (*What about people from your ethnic background? Is computing popular? Why/why not? Do you think your ethnic background makes it easier or harder to succeed in computing?*).
- Gender, would girls find it more appealing than computing?

Any other things you would like to discuss?

Learning pathways of digital creatives: A case study of a computing summer school

Dear Parent/Guardian,

We would like to invite your child to participate in a research project. Before you decide whether to give permission for your child to take part, it is important for you to understand why the research is being done and what participation will involve. Please take time to read the following information and if there is anything that is not clear or you would like more information on, our contact details are at the end of this information sheet.

What are we doing?

We are based in the School of Education at the University of Roehampton and we are interested in ways that students become digitally creative. We will be talking to participants in the #### summer school and we would be very grateful if you would consider allowing your child to participate. Please note that your child does not need to take part in this study in order to attend the summer school. It is entirely optional.

What will the benefits of the project be?

By taking part, your child will be making a valuable contribution to the knowledge of educational researchers and professionals. In particular, we hope the project will increase awareness of the views, experiences and skills of young people in relation to digital creativity. In particular we wish to highlight their use of 3D digital animation tools.

What will participation involve?

If your child participates, he/she will be interviewed after the summer school. The interview will take approximately 40 minutes. No preparation is required and your child is free to express any views or opinions he/she wishes.

Additionally your child will be part of a 'studio' at the summer school. Each studio will be tasked with making a film over the course of the 7 day summer school. Close observations of several of these studios will be made, noting interactions between students and technology, and students and other students.

Participation is voluntary and your child does not have to answer any questions that they don't want to or to have their interactions observed and recorded. You or your child have the right to withdraw from the study at any point and do not have to give a reason for doing so. With your child's consent, the interview will be audio recorded, and later written up. Observations will include their interactions being recorded through note taking and film. All interviews and observations will be treated as strictly confidential and will be fully anonymised. No one will be able to identify your child or their school. Data will be archived for use by other researchers only in anonymous form.

What do I do next?

If you are happy for your child to take part, please sign the enclosed consent form, and return the form by mail, or when attending the summer school. We will then arrange a suitable time after the week of the summer school for the interview to take place. If applicable, observations will happen throughout the week.

Contact Details

Peter Kemp, School of Education, University of Roehampton, SW15 5PJ, Tel: 020 8392 3583, peter.kemp@roehampton.ac.uk

PARENTAL PARTICIPANT CONSENT FORM

Title of Research Project: Learning Pathways for Digital Creativity

Brief Description of Research Project, and What Participation Involves:

This study aims to find out about the learning pathways taken by young digital creatives. We hope that by understanding their learning journeys, we will be able to provide a better computing education for many young people. By taking part in this study, we will ask your child some questions about computers, technology and around their education and backgrounds. Your child might also be observed making their 3D digital movie.

My information/contact details:

Peter Kemp, School of Education, University of Roehampton, SW15 5PJ, Tel: 020 8392 3583, peter.kemp@roehampton.ac.uk

Consent Statement:

I agree that my child (named below) can take part in this research, and am aware that he/she is free to withdraw at any point without giving a reason, although the data collected might still be used in a collated form. I understand that the information my child provides will be treated in confidence by the investigator and that his/her identity will be protected in the publication of any findings, and that data will be collected and processed in accordance with the Data Protection Act 1998 and with the University's Data Protection Policy.

Child name …………………………………   Your name ………………………………….

Signature ………………………………   Date ……………………………………

Please note: if you have a concern about any aspect of participation in this research or any other queries please raise this with the investigator or their Director of Studies. However, if you would like to contact an independent party please contact the Head of Research.

Director of Research Contact Details: Professor Vini Lander, School of Education, University of Roehampton, SW15 5PJ, Tel: 020 8392 3865, vini.lander@roehampton.ac.uk

Director of Studies: Professor Debbie Epstein, Cedar 108, Froebel College, School of Education, University of Roehampton, SW15 5PJ, Tel: 020 8392 3768, Debbie.Epstein@roehampton.ac.uk
[Please keep one copy for your reference]

Learning pathways of digital creatives: A case study of a computing summer school

University of Roehampton London

Dear Student,

We would like to invite you to participate in a research project. Before you decide whether to give your permission to take part, it is important for you to understand why the research is being done and what participation will involve. Please take time to read the following information and if there is anything that is not clear or you would like more information on, our contact details are at the end of this information sheet.

What are we doing?
We are based in the School of Education at the University of Roehampton and we are interested in ways that students become digitally creative. We will be talking to participants in the #### summer school and we would be very grateful if you would participate. Please note that you do not need to take part in this study in order to attend the summer school. It is entirely optional.

What will the benefits of the project be?
By taking part, you will be making a valuable contribution to the knowledge of educational researchers and professionals. In particular, we hope the project will increase awareness of the views, experiences and skills of young people in relation to digital creativity. In particular we wish to highlight your use of 3D digital animation tools.

What will participation involve?
If you participate, you will be interviewed after the summer school. The interview will take approximately 40 minutes. No preparation is required and you are free to express any views or opinions you wish.

Additionally you will be part of a ‘studio’ at the summer school. Each studio will be tasked with making a film over the course of the 7 days. Close observations of several of these studios will be made, noting interactions between students and technology and students and other students.

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Contact Details Peter Kemp, School of Education, University of Roehampton, SW15 5PJ, Tel: 020 8392 3583, peter.kemp@roehampton.ac.uk

University of Roehampton London

STUDENT PARTICIPANT CONSENT FORM

Title of Research Project: Learning Pathways for Digital Creativity

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This study aims to find out the learning pathways taken by young digital creatives. We hope that by understanding your learning journeys, we will be able to provide a better computing education for many young people. By taking part in this study, we will ask you some questions about computers, technology and around your education and background. You will be interviewed at a convenient time after the summer school and it should take around 40 minutes. You might also be observed making your 3D animation and details about your participation recorded.

My information/contact details:
Peter Kemp, LU019, School of Education, University of Roehampton, SW15 5PJ, Tel: 020 8392 3583, peter.kemp@roehampton.ac.uk

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Name ………………………………….

Signature ……………………………… Date ……………………………………

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Such media may be visible worldwide (where UK law may not apply), e.g. via the website. It may be presented without time limit. We may authorise other individuals and organisations to use such media, e.g. the press.

The student's name will be included in the credit roll of the short film they create, which will then be posted publicly online. A student may choose to have their name excluded, it is up to them to tell their producer/director during the event.

I consent to my son/daughter being photographed/filmed at #### and for this media to be used as stated above. I confirm that I have legal responsibility for this individual and am entitled to give this consent.

Name: ____________________________________

Parent/Guardian of: ____________________________________ (name of student)

Address:

____

____

Postcode: __________________

Signature:_________________________ Date: ---------_________________

All information is collected in accordance with the GDPR and any subsequent legislation

Note that if you are 18 years old or older you may fill in this form yourself.